Moisture-related failures of operational amplifiers in plastic packages

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Purpose

- To review statistics of HAST failures in linear devices encapsulated in plastics.
- To estimate the acceleration factor and mechanism of failures.
- To discuss results of environmental stress testing and the risk for space applications.

Outline

- Statistics of op-amp failures.
- Test plan.
- Results of accelerated testing.
- Results of failure analysis.
- Mechanism of failures.
- Results of environmental stress testing.

HAST test conditions

Preconditioning per JESD22 – A113-B:
moisture soak for 168 H @ +85C/85%RH, 3 cycles of solder reflow at @ + 220C, flux immersion for 10 sec, rinsing in deionized water.

HAST conditions: T = 130 ^{o}C, RH = 85 %, t = 250 hrs, electrical bias.

Sample size: each lot 30 samples.

SMT simulation and HAST results

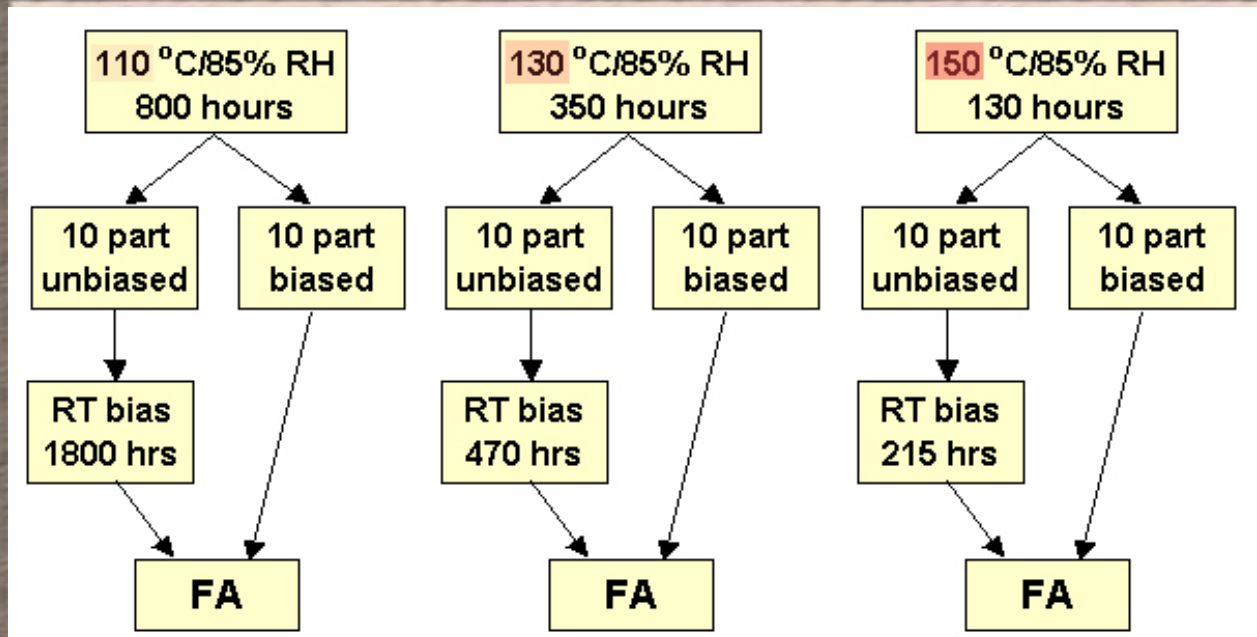
Part	Type	Pack	DC	SMT	HAST	Comm.
OP1	Instr.	SOIC8	0030, 0110	1/30, 0/30	30/30, 27/30	Param. failures
OP2	Quad	SOIC16	0101	16/30	2/30	SMT: IOS and AOL HAST: init.+1 new
OP3	Instr.	SOIC8	0022, 9628	0/16, 0/16	0/16, 0/16	
OP4	Bandw	SOIC8	0018	0/30	0/30	
OP5	Bandw	SOIC8	0041	0/30	0/30	
OP6	Dual	SOIC8	0033, 0109, 9946	0/30, 0/30, 0/30	0/30, 0/30, 1/30	Possibly reverse installation
OP7	Precis.	SOIC8	0019, 0021, 0029	0/30, 0/30, 0/30	0/30, 0/30, 0/30	
OP8	Quad	SOIC16	9945	2/30	0/28	

Statistics of HAST Failures

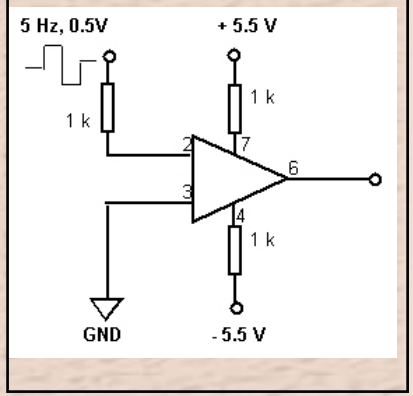
- Out of 8 different op-amps in SOIC-8/16 packages, only one part type consistently failed HAST with 90% to 100% of failures.
- This might indicate an early wear out mechanism and is a reliability concern for space instruments, which require 2 to 5 years of the ground phase testing and storing at normal conditions.

Test Plan

- Two groups of op-amps were tested under bias and without bias at three temperatures and 85% RH for up to 800 hrs.
- After HAST the parts, which were tested without bias, were biased at RT for up to 1300 hrs.
- Characteristics were measured periodically through the testing.

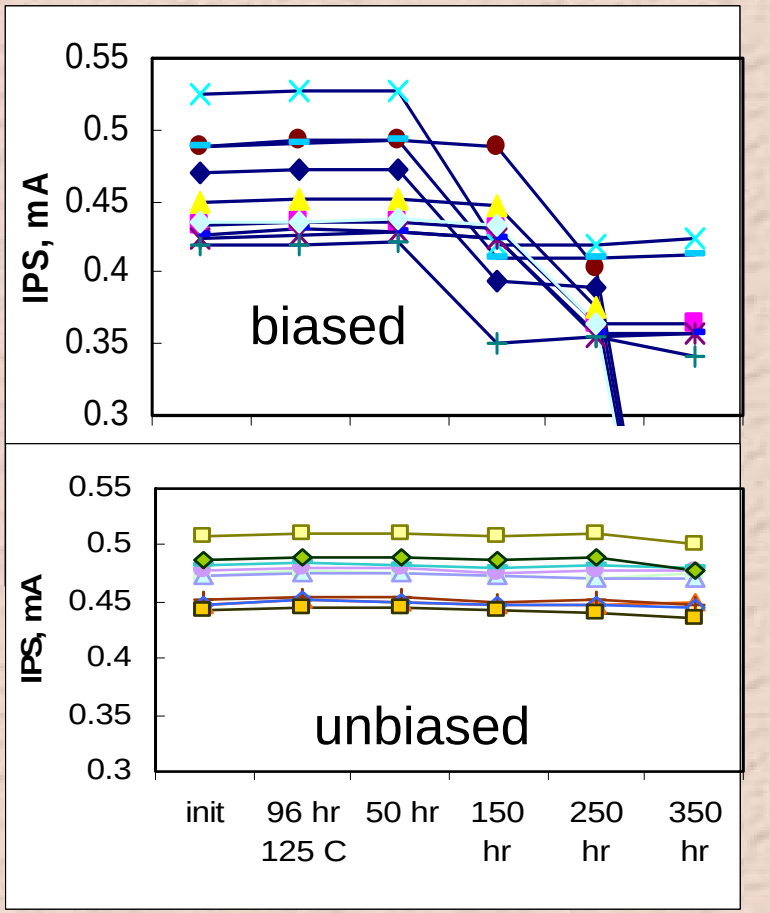


HAST bias schematic

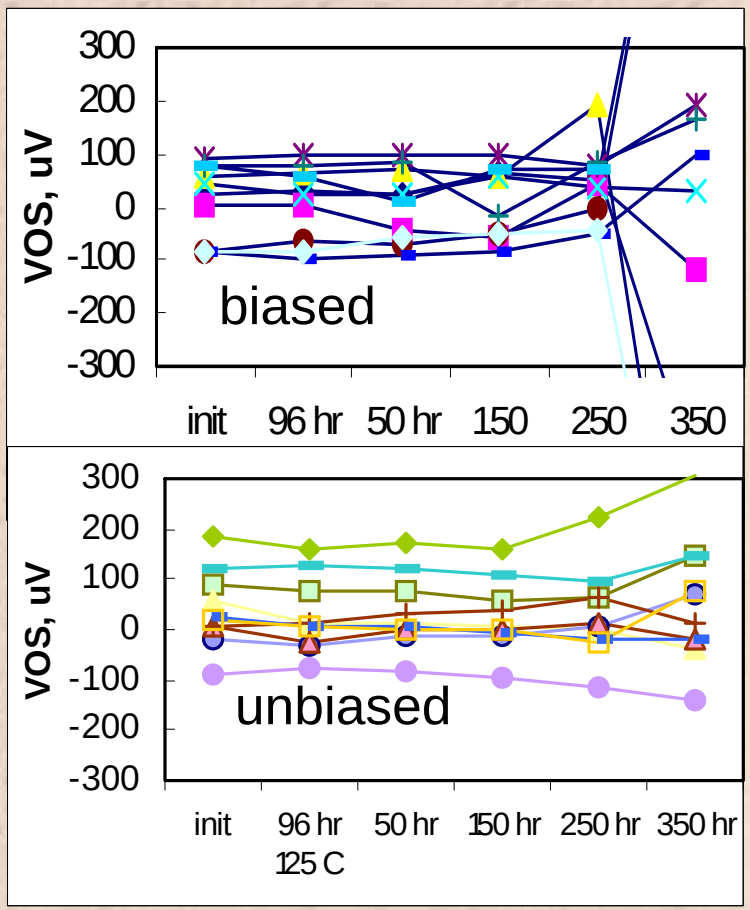


Test Results at 130 ºC HAST

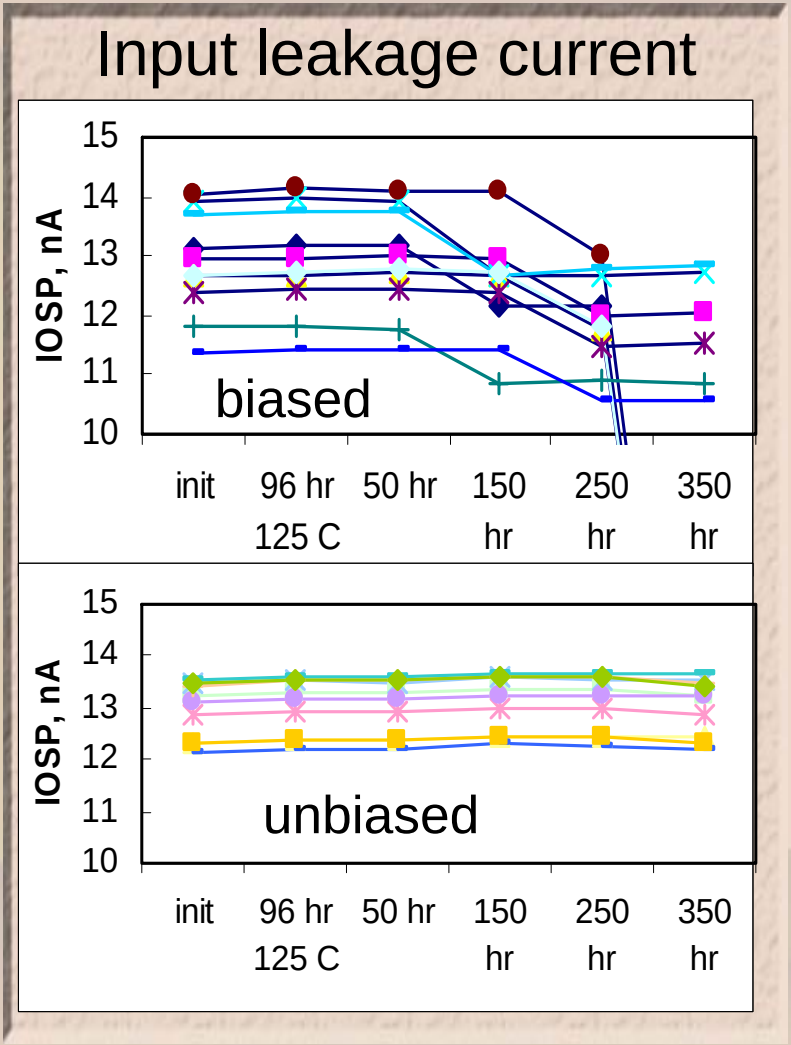
Power supply current



Offset voltage



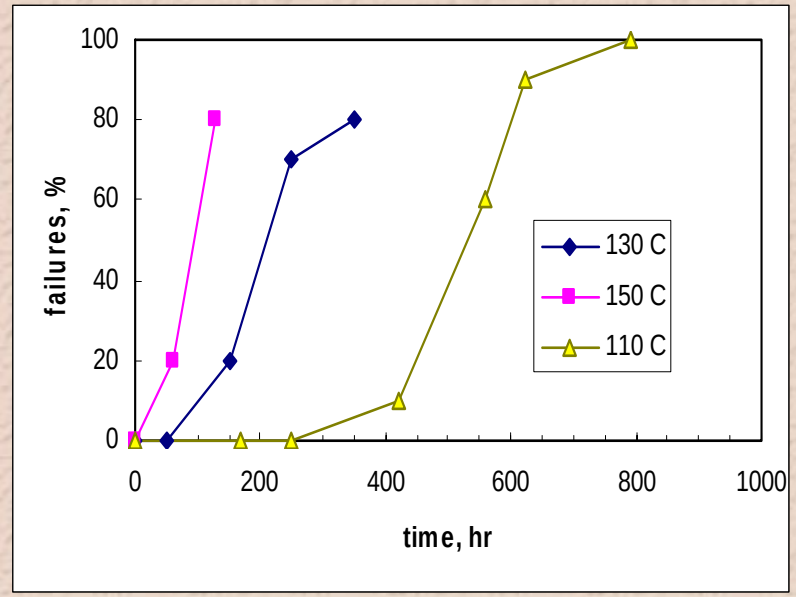
Test Results at 130 ºC HAST, Cont'd



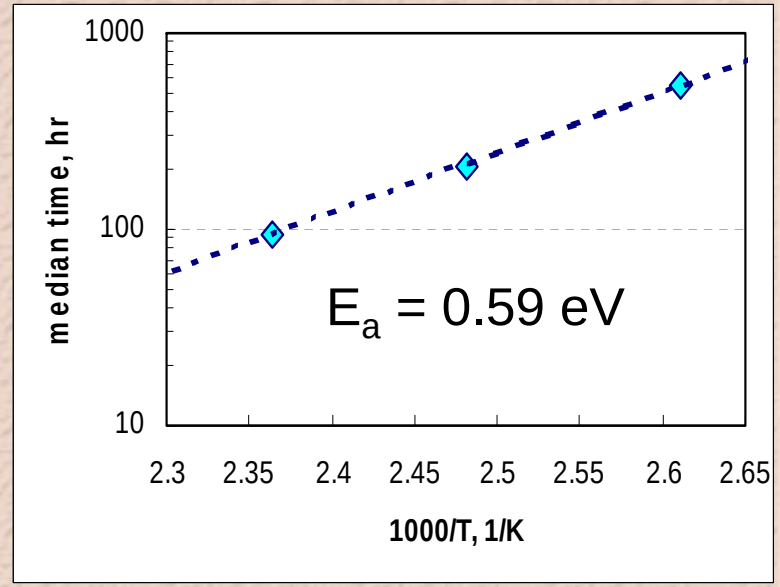
- No failures and/or parametric shifts for unbiased parts.
- Drop of IPS coincided with decrease of IOS.
- Similar degradation in IPS and IOS was observed during HAST at 110 and 150 ºC.
- Failure condition: 10% decrease in IPS.

Distribution of Biased HAST Failures

Failures during biased HAST

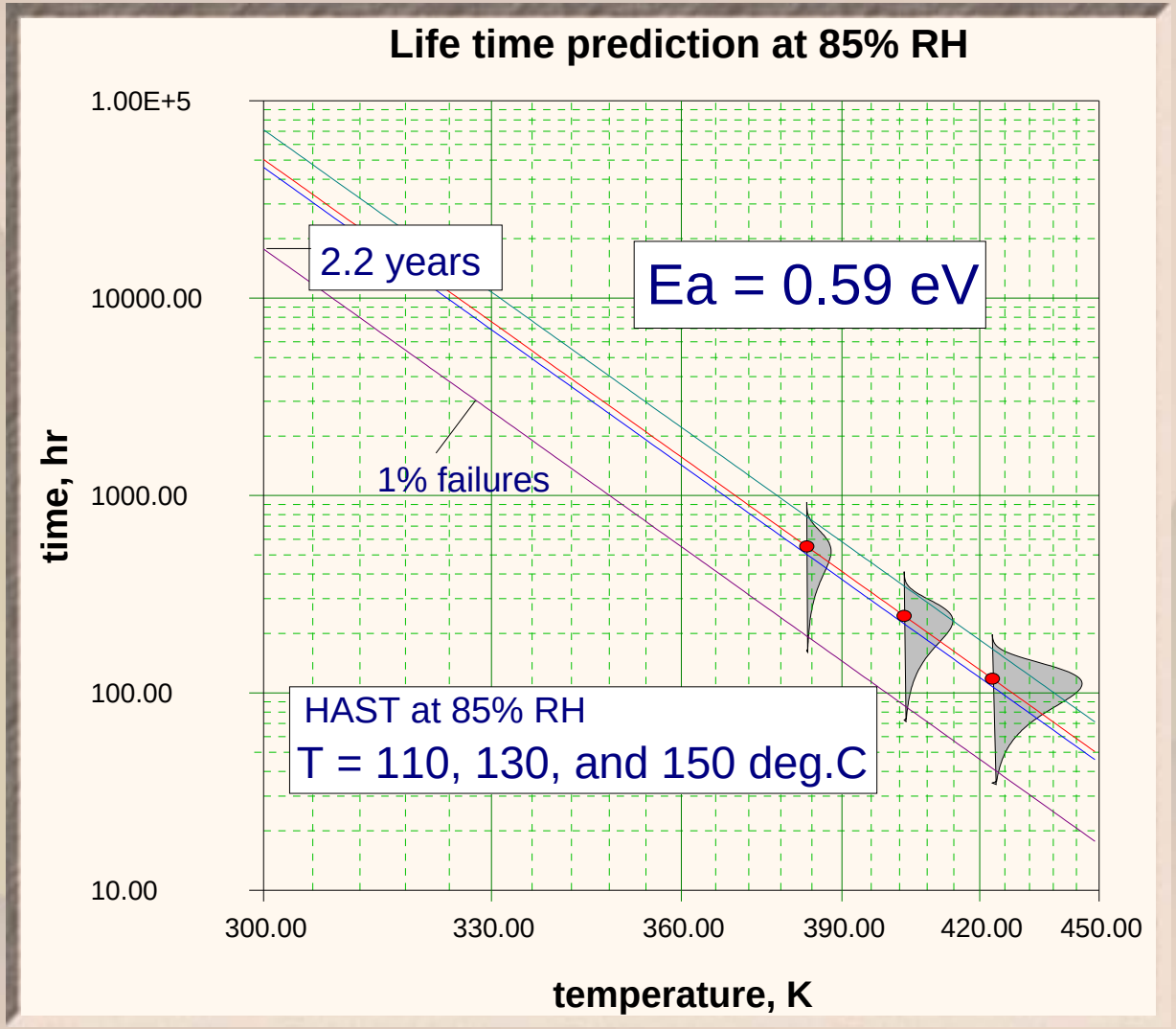


Arrhenius plot of median life



- HAST per JESD22-A110B, 130 ºC/96hrs, might not reveal these failures.
- Ea is lower than in Peck-Hallberg model (0.79 -1.1 eV). This increases the probability of failures at low T.

Arrhenius-Weibull model



Life Time Prediction for LT Operation

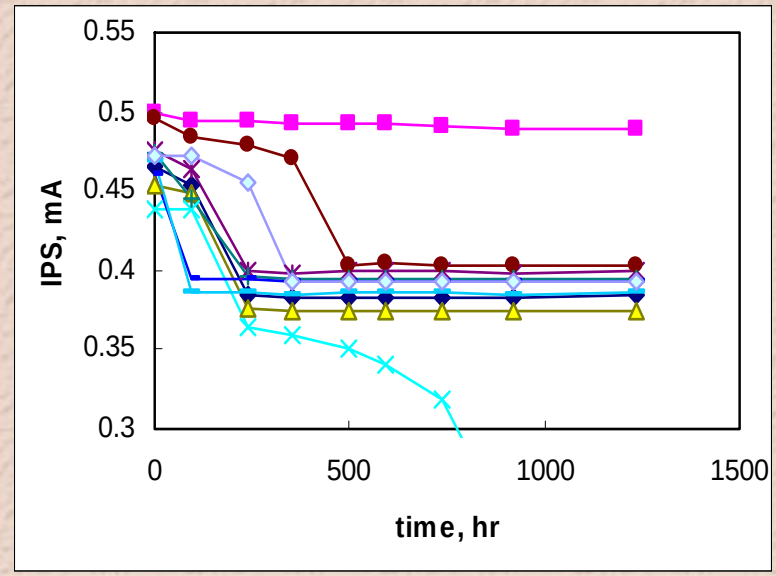
- Based on Arrhenius-Weibull model, 1% of the parts operating at 85% RH at RT are expected to fail after ~2.2 years.
- Based on Pecht- Hallberg model (1<n<5), the proportion of failures at 50% RH would be 0.6 to 0.07%.

$$t_f = A(RH)^{-n} \exp\left(E_a / kT\right)$$

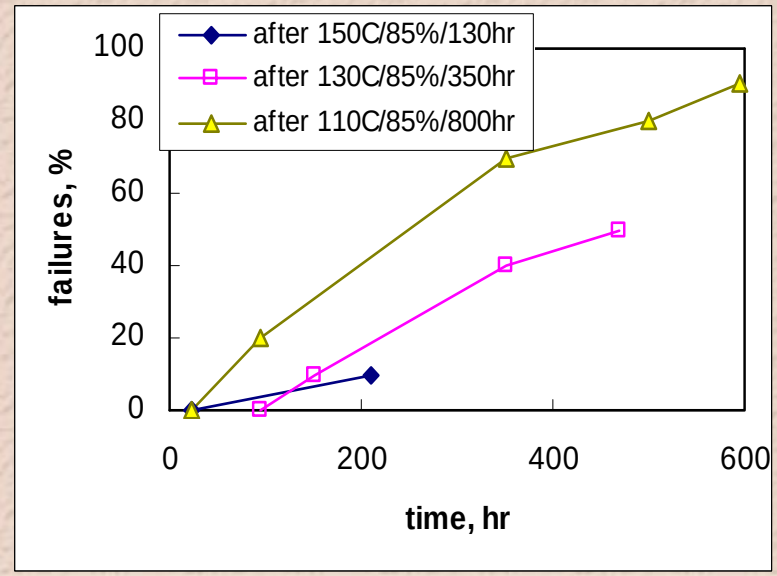
- Due to the capillary effect, a weak dependence of failures on relative humidity is possible.

Biased Testing at RT after Unbiased HAST

RT bias testing after 110 ºC HAST for 800 hrs



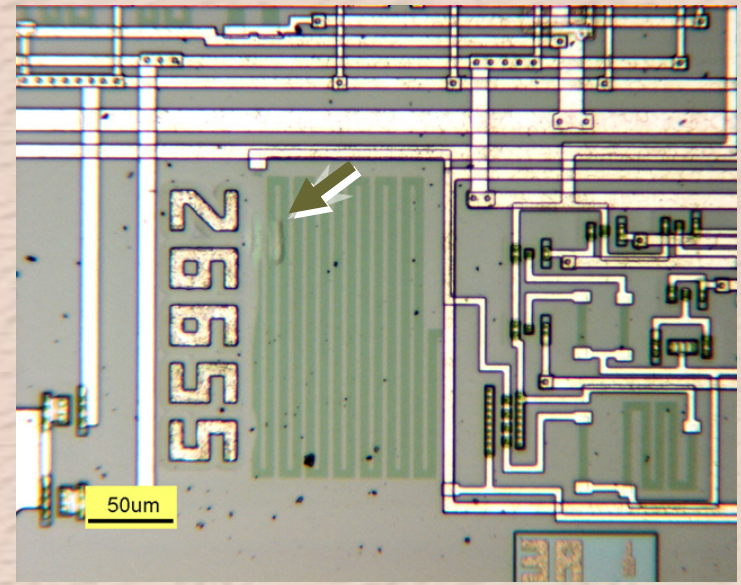
Failures during RT testing followed unbiased HAST

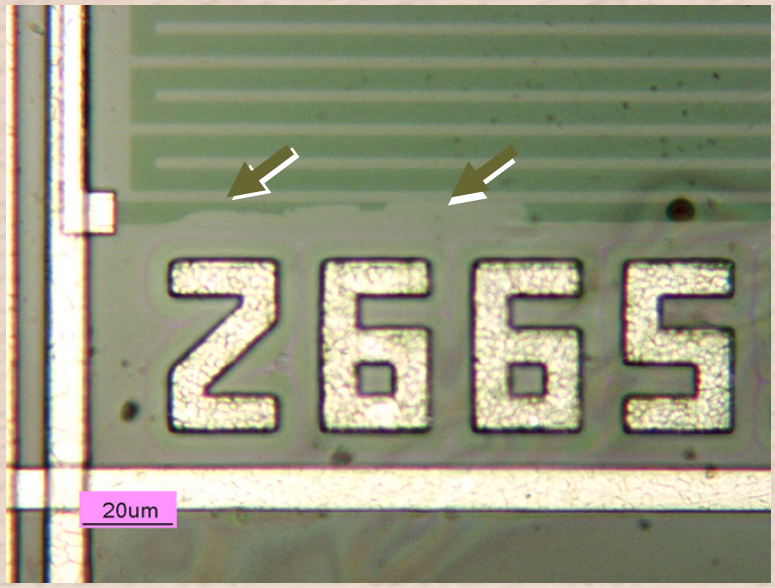


- RT testing followed unbiased HAST resulted in failures in 24 to 600 hours.
- Temperature during HAST does not seem to affect significantly the RT test results.

Analysis of Failed Parts

FA result: corrosion of thin film resistors

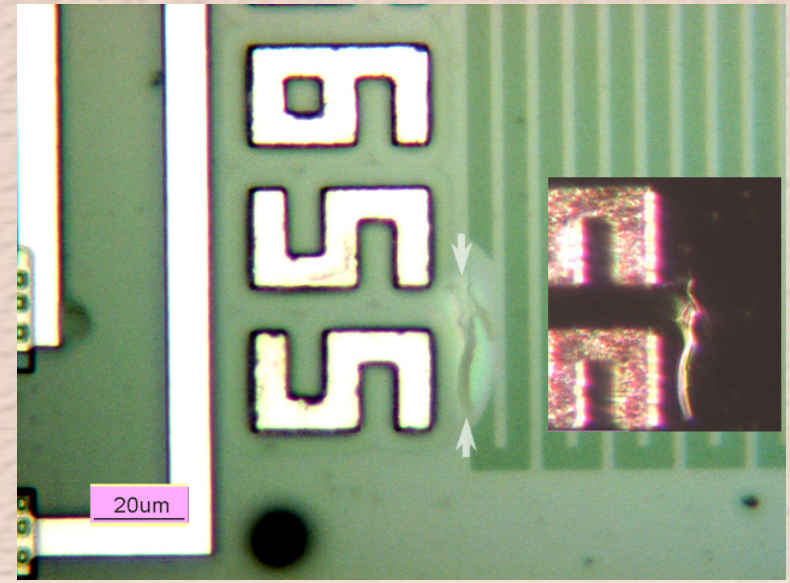




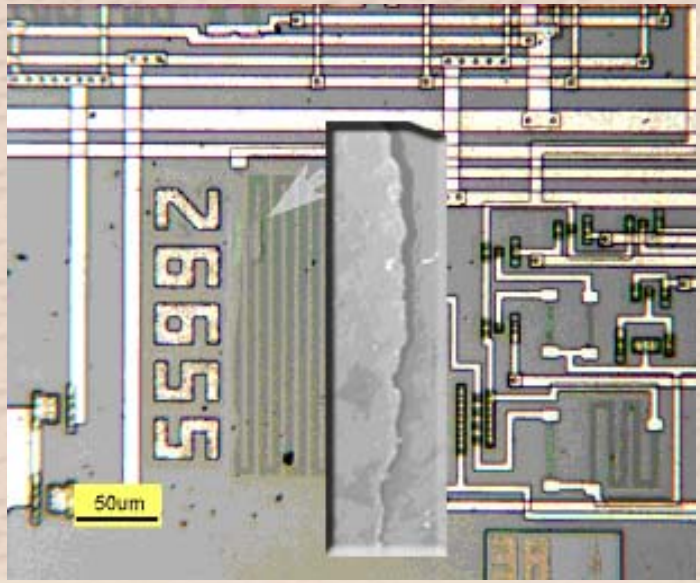
Most failures during biased HAST exhibited a missing section of a chromium thin-film resistor.

Analysis of Failed Parts, Cont'd

A dark-field view insert shows a rupture of the glassivation.

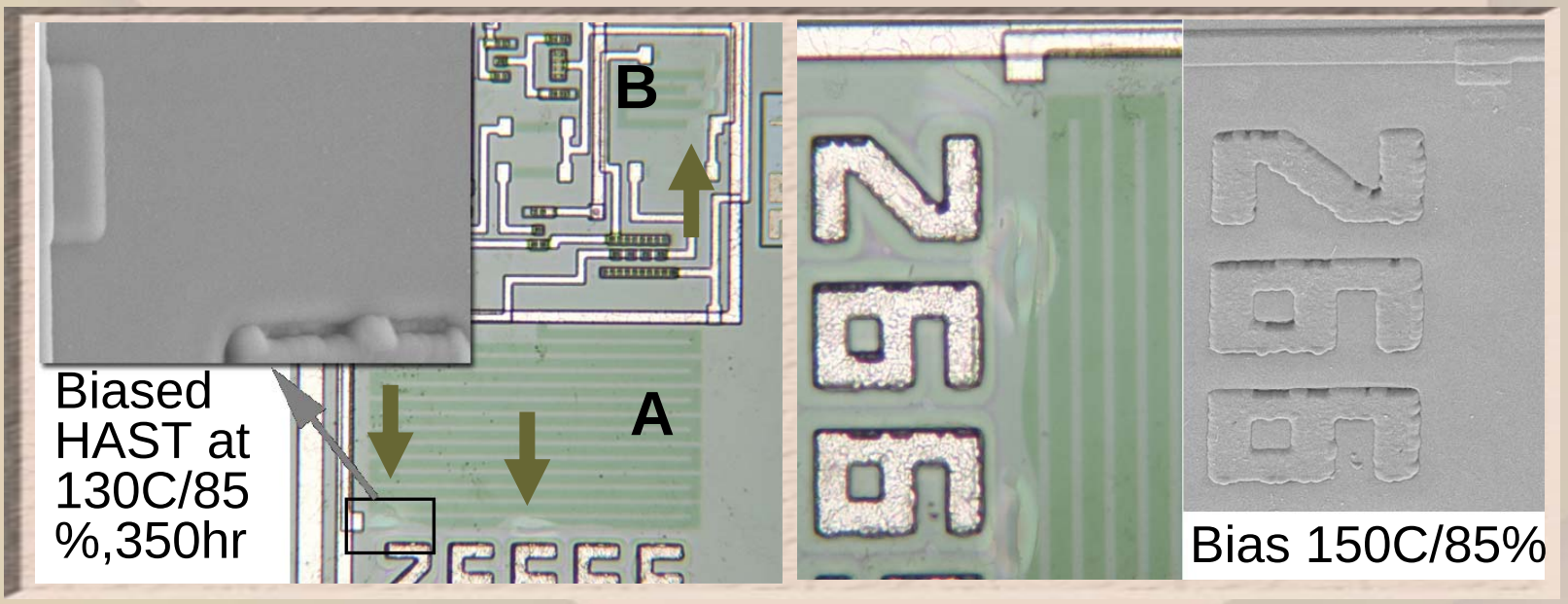


SEM view insert shows a crack in the glassivation



- All failures had damage to the first stripe (+bias) close to marking numbers in 1 MΩ Cr/Si resistors.
- In some cases missing sections of resistors were associated with cracks in passivation.

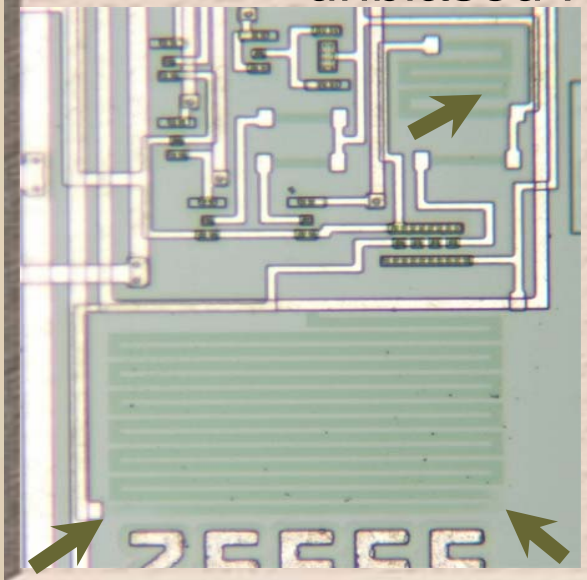
Analysis of Failed Parts, Cont'd

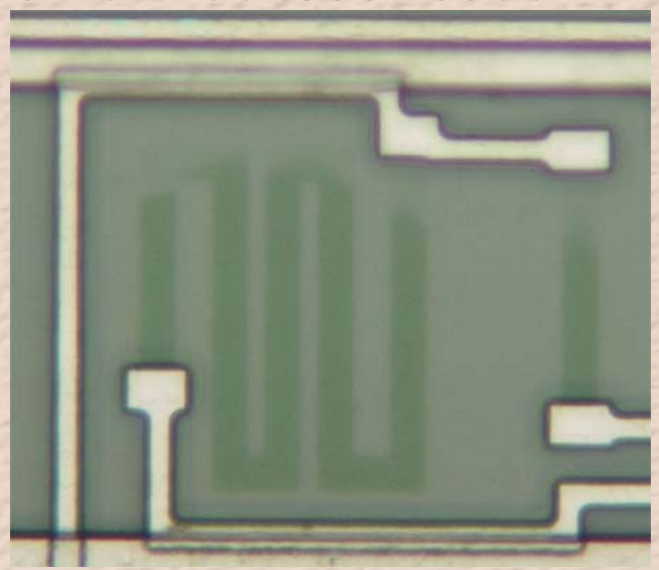


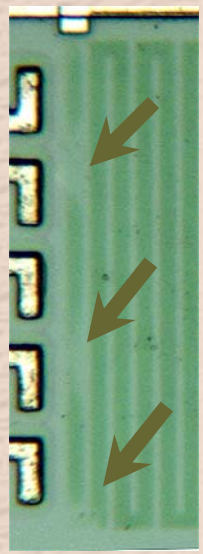
- In many cases no cracks in the glassivation were observed during SEM examination.
- In several cases resistors B also had missing portions on the side close to aluminum stripe.

Analysis of Failed Parts. RT Testing after Unbiased HAST

Different samples after 470 hrs of RT bias followed unbiased HAST at 130C/85%/350 hr



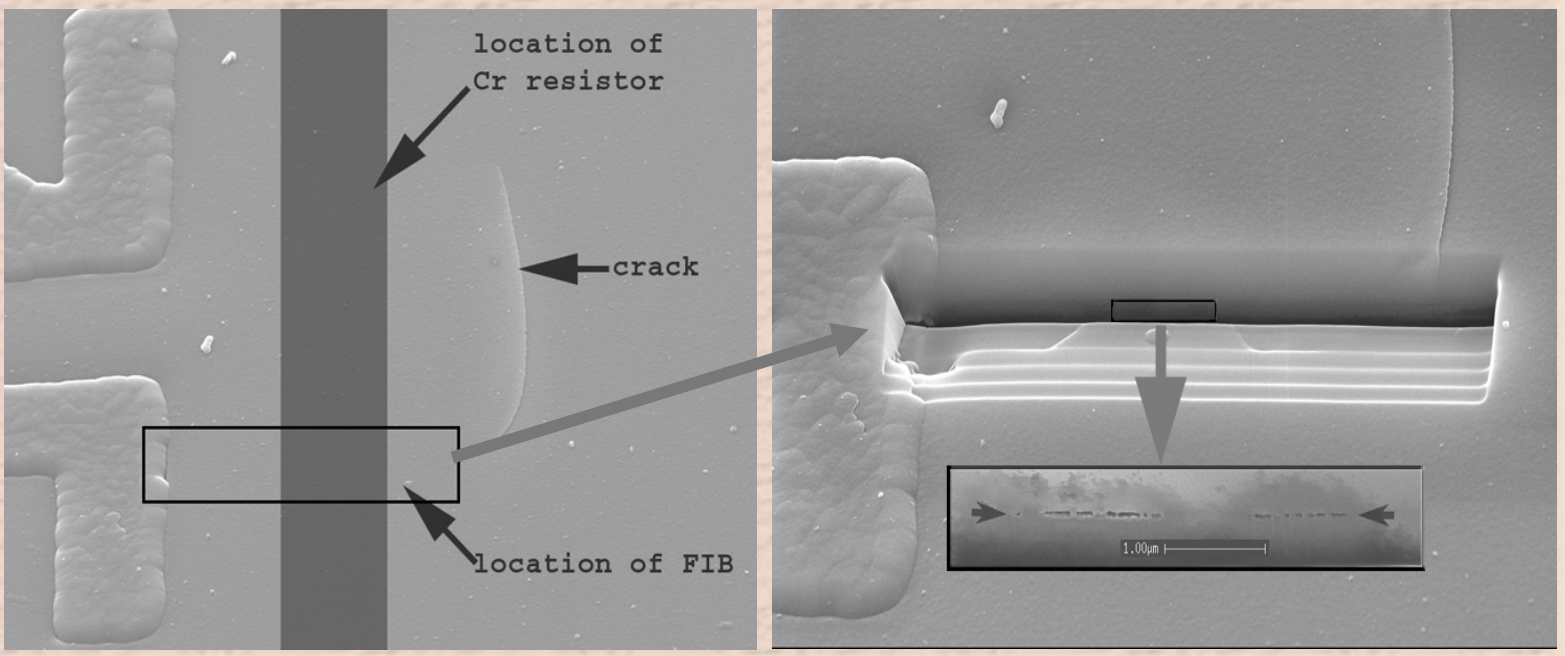




RT testing of moisturized samples resulted in corrosion of Cr/Si resistors similar to HAST failures.

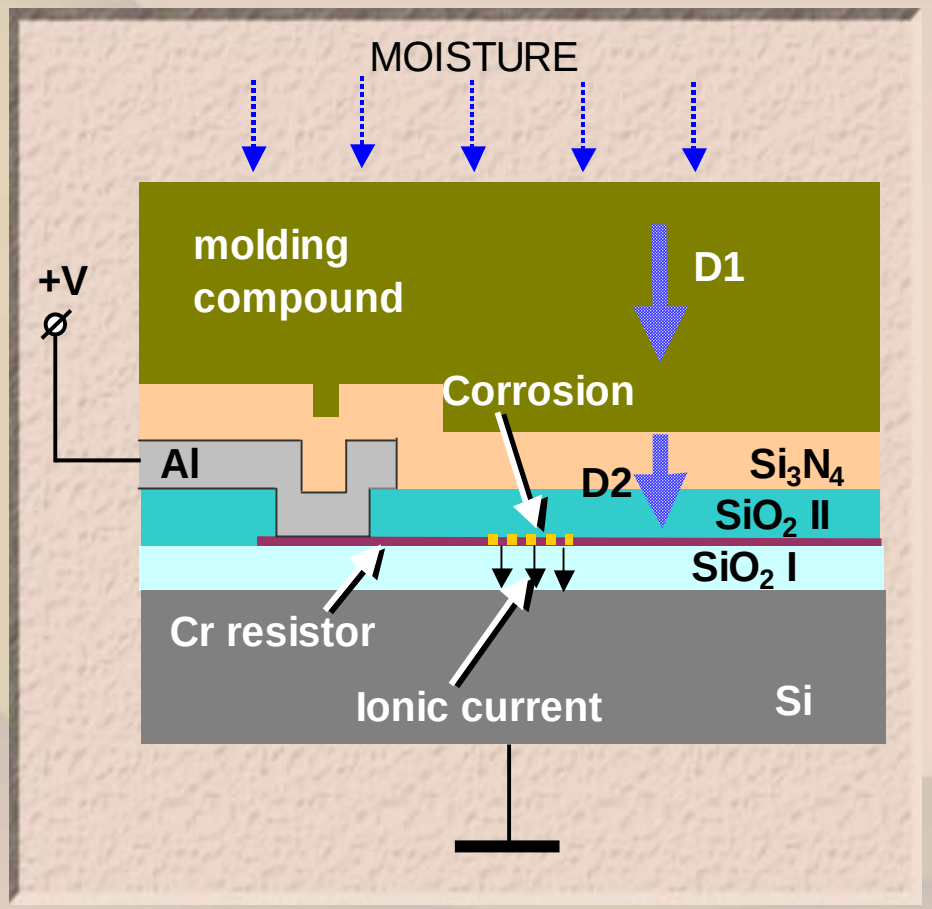
Analysis of Failed Parts, Cont'd II

FIB trench of the failed part at the cracking glassivation



- Locations of crack and missing section of resistor do not coincide.
- Voiding in nitride/oxide might contribute to the failures.

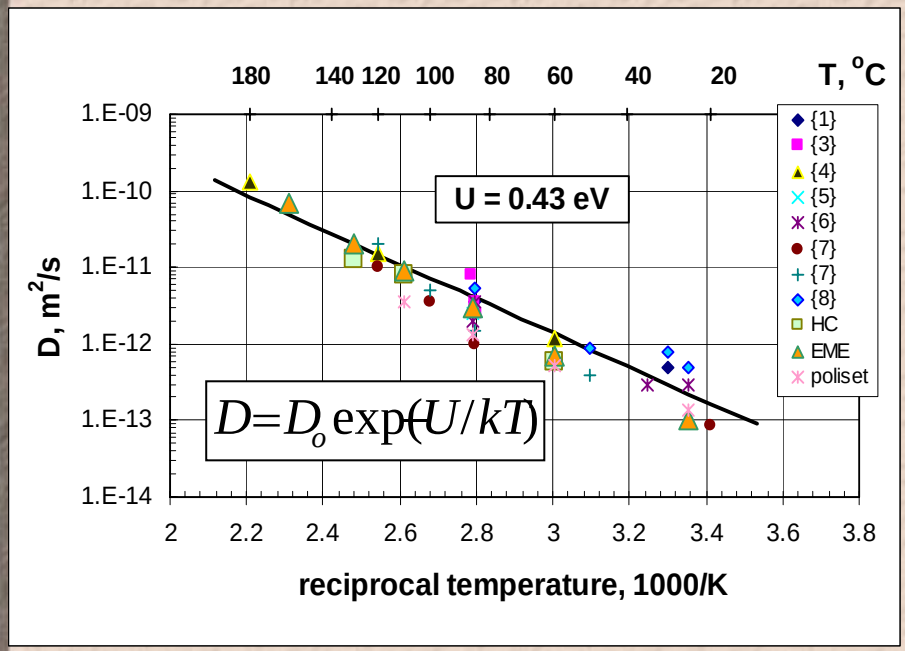
Limiting Factors of Degradation



- Failures were due to both the presence of moisture and applied bias, thus indicating anodic corrosion.
- Possible limiting factors for corrosion failures:
  - Diffusion through MC;
  - Galvanic process;
  - Diffusion through Si_3N_4/SiO_2

Limiting Factor I: Moisture Diffusion through Plastic Package

Characteristics of different MCs



Time to moisture saturation [$C(0)/C_o$ = 99%] in MC:

$$\tau(T) = 12 \times h^2 \times [\pi^2 \times D(T)]^{-1}$$

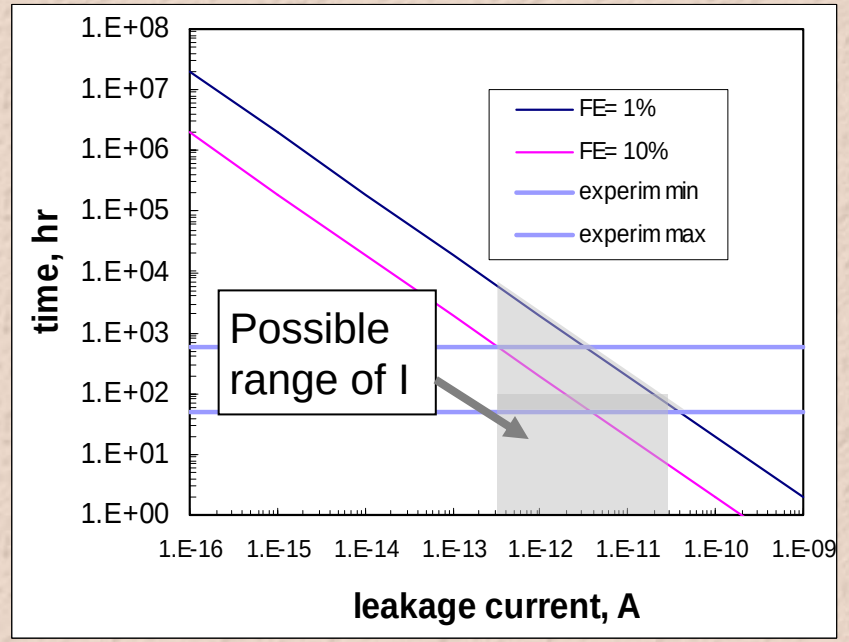
h = 0.5 mm is the thickness of MC above the die.

Temp, °C	τ, hr
150	2.3
130	4.2
110	8.2
25	380.4

- Moisture diffusion through plastic does not limit HAST failures.
- At RT package can keep moisture for ~2 weeks only.

Limiting Factor II: Anodic Corrosion of Cr/Si Resistor

Time to corrosion failure at RT



According to Faraday's law, the time necessary to remove a portion of the resistor of a volume ΔV, 50X10X0.005μm:

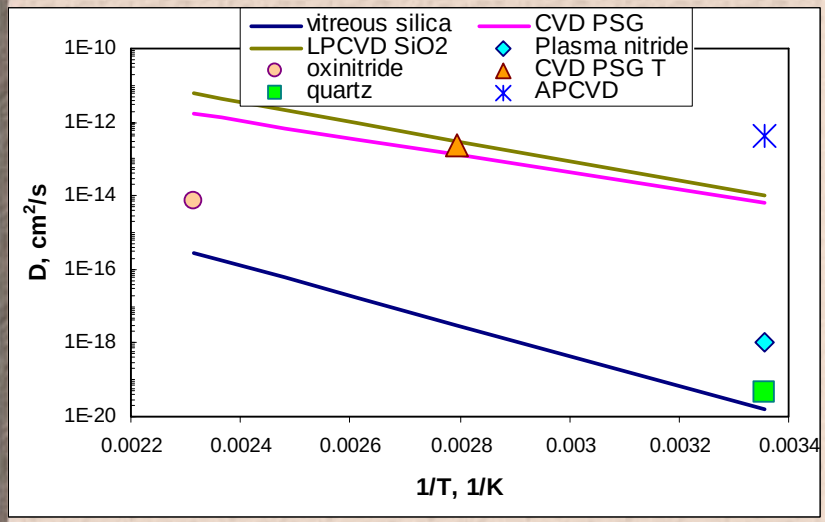
$$\tau = \frac{\Delta V \times n \times F}{\rho \times \eta \times A \times I}$$

At Ea ~0.5 eV, increase in T to 110 – 150 °C would increase conductance in 90 to 400 times.

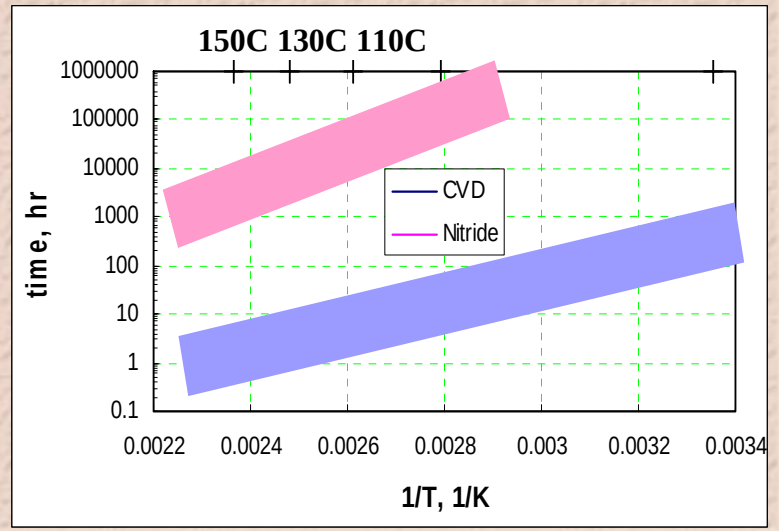
- At RT failures might be caused by moisture-induced I_{leak} in the picoamp range during 10X to 100X hrs.
- At HT (110 to 150 °C) this time is reduced to hours, so the galvanic process is not a limiting factor of failures.

Limiting Factor III: Moisture Diffusion through Si_3N_4 passivation and CVD SiO_2

Literature data on moisture diffusion in silica-based materials

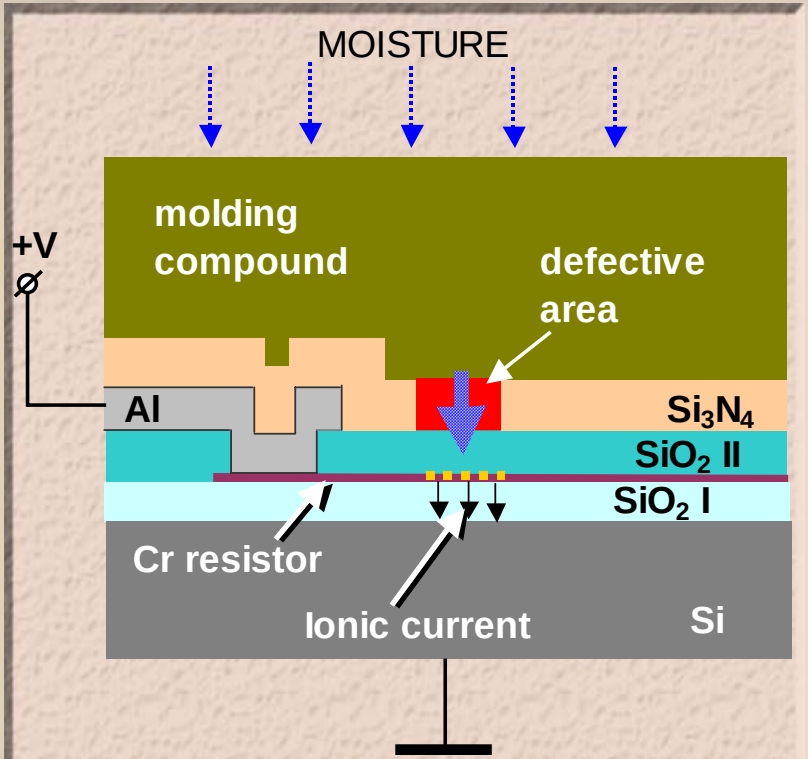


Time for moisture diffusion through Si_3N_4 and SiO_2. $\tau = h^2/D(T)$, h = 1 μm



- At 110<T<150 ºC diffusion through CVD SiO_2 takes < 10hrs.
- From 100 to 10,000 hrs is necessary to penetrate through the layer of nitride passivation.

Failure Mechanism

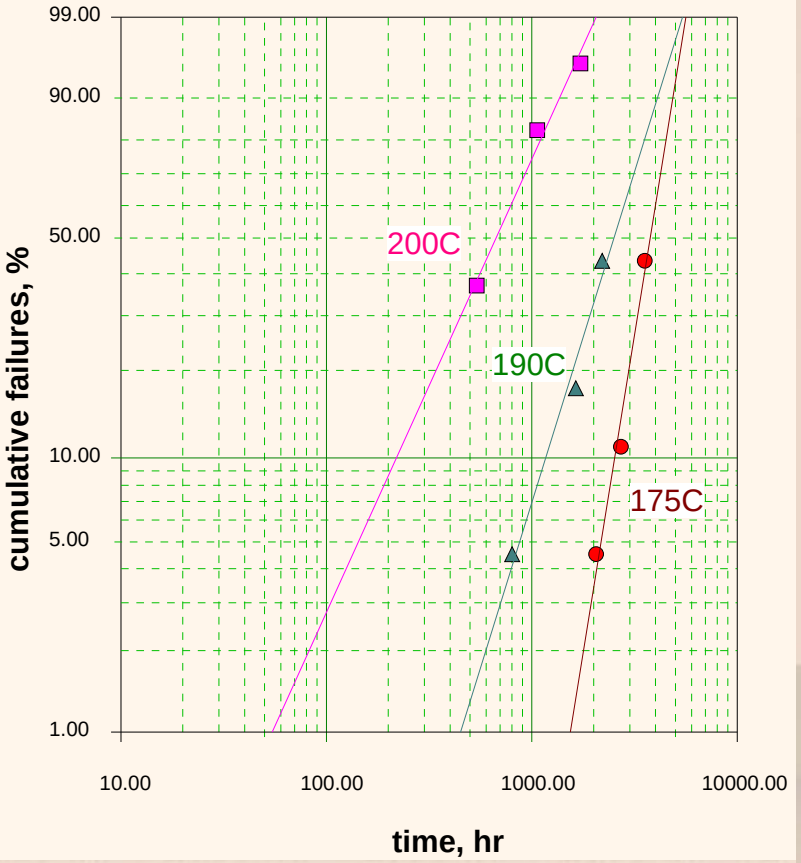


- Normally, Si_3N_4 layers are impermeable to moisture and time-to-HAST failure >1000 hrs.
- Missing portions of resistors were mostly observed on stripes close to Al metallization.
- Unevenness of the structure, excessive contamination and/or mechanical stresses in areas close to Al stripes possibly resulted in defects in Si_3N_4.

Microcracks or micropores in defective areas of passivation enhance moisture diffusion and activate galvanic current in the underlying SiO_2 I layer causing corrosion of Cr/Si resistors.

Evaluation of Risks for Space Applications, HTSL.

Parametric failures (VOS) during HTSL at 175, 190, and 200 °C.



- Moisture released during HT aging of MC could have caused corrosion failures at T>>130 °C.
- FA: failures were not related to corrosion.
- Median life Ea ~1.05 eV.
- Assuming Weibull distribution for 150 °C at β = 7.7 and η = 29,653 hr, the time to 1% failure is ~1.9 years.

No risk for the mission during long-term storage.

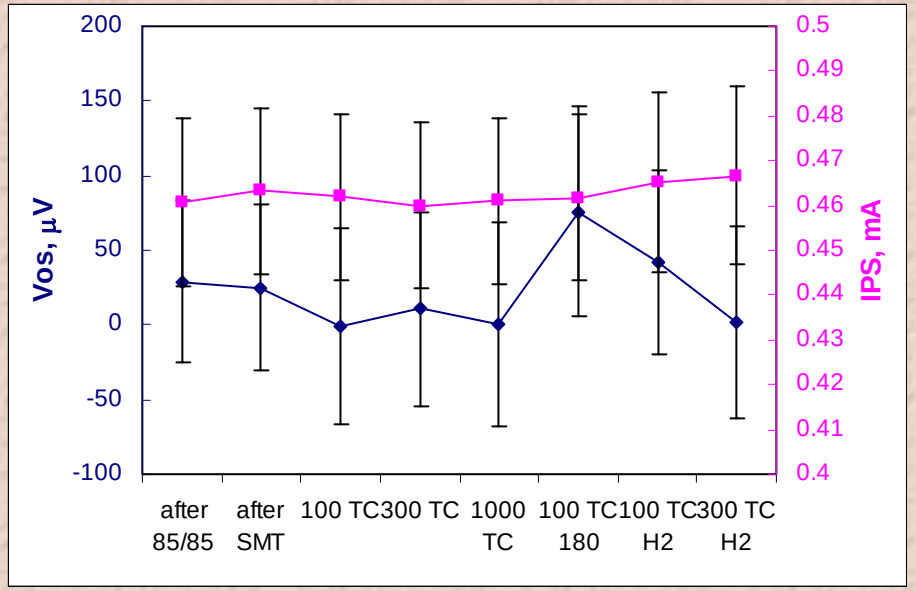
Evaluation of Risks for Space Applications, TC

SMT/TC test conditions (30 samples):

- SMT simulation per JESD22-A113 ;
- 1000 TC –55 to +125 ºC (condition TC0);
- 300 TC 0 to 180 ºC (condition TC1);
- 300 TC 20 to 200 ºC (condition TC2).

No risk for the space mission during multiple TC.

VOS and IPS variations during SMT and TC testing



Devices had minor parametric variations and no failures

Conclusion

- Wearout failures of instrumental op-amps during HAST were due to corrosion of thin film Cr/Si resistors.
- Unbiased HAST did not cause failures; however, post-HAST testing under bias at RT resulted in failures similar to biased HAST.
- The activation energy of failures is 0.59 eV.
- Arrhenius-Weibull model predicts 1% failures for the parts operating at RT and 85% RH after ~2.2 years.
- The limiting factor in corrosion failure is moisture diffusion through microscopic defects in passivation layers.
- A combination of unbiased HAST with RT bias testing might be a good alternative to biased HAST for QA of parts intended for space applications.