Transistor Bonding Wire Corrosion in Type TO Cans

J. Drake, C. Beck, and R. Libby

Wire-to-post bonds of silicon transistors in hermetic TO type packages are reliably corrosion resistant. A field failure rate of 0.21 ppm is attributed to random, uncontrolled contaminants acting in conjunction with excessive moisture. An exhaustive effort to replicate such failures employing high temperature and humidity in the absence of deliberately introduced contaminants was unsuccessful.

Keywords
bonding wires, corrosion, humidity, microelectronics, reliability

1. Introduction

RANDOM low level failure rates of hermetically sealed metal can transistors have sometimes been ascribed to bond wire-to-post corrosion (Ref 1). These transistor devices assembled in TO type packages exhibit open circuit failure of aluminum bonding wires. This failure mode appears to be accompanied by an amorphous corrosion material at the aluminum wire-to-post bond, leading to thinning of the useful cross section of the conductive bond wire. An extreme example of the failure mode is shown in Fig. 1.

It has been generally accepted in the industry that four factors are necessary to corrode electronic device packaging materials. These are (a) dissimilar metals (i.e., Au + Al in contact with each other), (b) enough H_2O to collect at the interface of dissimilar metals, (c) an electrolyte present at the interface of dissimilar metals, and (d) time.

Given the presence of these four factors, there are two schools of thought with regard to the reaction itself. (a) The reaction is self-limited by the consumption of the electrolyte. This assumes the electrolyte is in finite supply and forms a stable by-product. (b) The reaction is driven by the consumption of available H_2O and/or Al. This theory assumes that the electrolyte will continue to be liberated as a reaction by-product.

Based on these concepts, the electronics industry has used two basic techniques, or a combination of them, for corrosion reaction acceleration. (a) High-temperature bake at 200 °C for 500 h provides energy to drive the reaction and is intended to represent three to five years of shelf plus use life (Ref 2). (b) Thermal/humidity cycling (Ref 2), typically –65 to +175 °C for up to 1000 cycles, releases the available H_2O for participation in the reaction and provides energy to help drive the reaction (Ref 3).

Electrical failure of the bond was observed in 21 cases of metal can devices out of 100 million manufactured by Raytheon Semiconductor since 1981. In these failures, the nature and physical composition of corrosion products were investigated. Scanning electron microscopy (SEM), electron dispersive analysis by x-ray (EDX), Fourier transform infrared (FTIR) spectroscopy, and Auger methods were used to identify the materials present and to form a basis for possible sources of contamination. The package construction of the TO package style assemblies was investigated for contaminants and manufacturing defects, including seal leaks. The internal gas content of the devices was analyzed for evidence of seal leaks, water content, and other manufacturing residuals using the residual gas analysis (RGA) technique.

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Our investigation with Auger methods confirmed the presence of small, variable amounts of sodium, potassium, and chlorine in all manufacturer packages investigated. These are known and expected plating components on gold-plated versions of TO-39 packages. In some cases, a residual "ring" was observed near the bond post-to-glass seal of the as-received manufactured header assembly (Fig. 2). Auger examination again indicated potassium and chlorine as the principal components within the "ring."

Initial corrosion evidence is frequently seen on devices after accelerated testing, but because of the limited availability of reactants required for corrosion within a sealed package, devices rarely corrode to electrical failure.

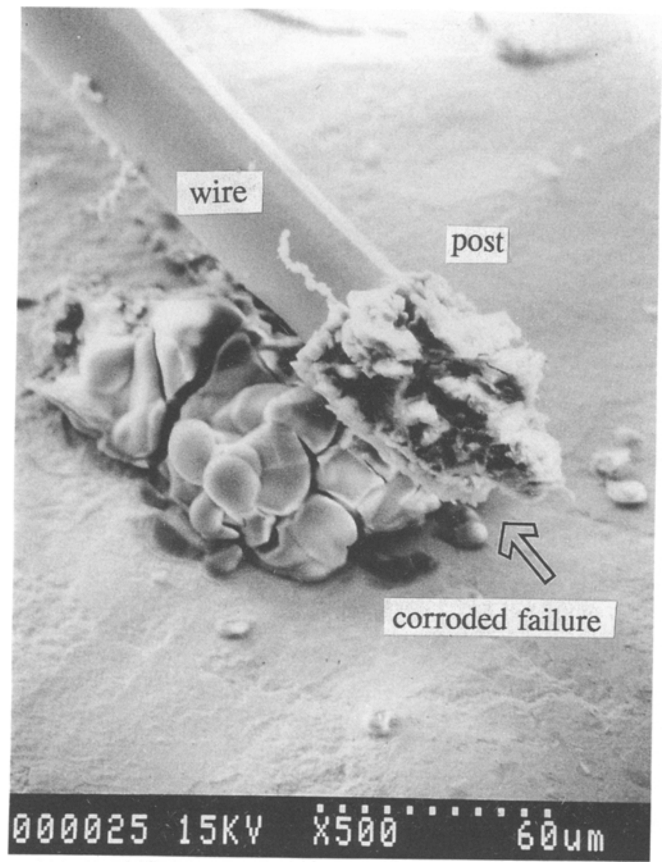

Fig. 1 SEM of aluminum wire bond-to-post failure. 500×

2. Analytical Techniques

The reliability consequences of moisture content in the TO packaged product were evaluated by accelerated testing on several manufacturers' transistors packaged in both nickel- and gold-plated versions of the TO-39 package. Three acceleration techniques were employed in these tests: temperature cycling from –65 to +175 °C; temperature and humidity stress, 85°C/85% RH (relative humidity); and chlorine bake test.

2.1 *Temperature Cycling from –65 to +175 °C*

The intent was to examine the effects of temperature cycling following an effort to accelerate any corrosion mechanism associated with sealed-in moisture. The method used was MIL-STD 883, method 1010 (Ref 4), with 1000 cycles between –65 °C for 18 min and +175 °C for 12 min, with negligible transition time between. Standard production parts were cycled from three different vendors and several different lots: Raytheon Semiconductor lot 1989R-5, 30 parts, Au plated; Raytheon Semiconductor lot 1989R-6, 20 parts, Ni plated; manufacturer A lot 1991A-1, 5 parts, Ni plated; manufacturer A lot 1991A-2, 5 parts, Ni plated; manufacturer A lot 1992A-3, 5 parts, Ni plated; and manufacturer B lot 19XXB-1, 5 parts, Au plated.

The two Raytheon Semiconductor lots were chosen as worst case examples of moisture content after the lots failed a RGA screening test where the criterion was zero failures of five packages per lot exhibiting a maximum limit of 5000 ppm moisture content. Manufacturer A typically had 1200 ppm moisture whereas manufacturer B had 10,000 ppm.

Following the 1000 cycle test, we verified that the moisture from the two Raytheon Semiconductor lots was within the range of 1100 to 21,000 ppm using RGA analysis on five random devices. SEM photos of a corrosion-free post of the device with highest moisture content, 21,000 ppm, are shown in Fig. 3 after 1000 cycles.

For measurement, three selected electrical test parameters at fixed intervals were monitored: VF_{beo} (one amp test), VF_{beo}, and BV_{ceo}.

2.1.1 VF_{beo} (One Amp Test)

This manual test forward biases the base positively across the base-emitter junction. The current is increased at approximately 300 mA/s to 1 V and is held there for approximately 3 s while the operator observes whether or not the trace remains stable. The current is reduced to 0 at about the rate of 1 A/s. The test is sensitive to changing resistance if parallel current paths fuse and form under stress. The test showed no instability at 551 and 1000 temperature cycles for Raytheon Semiconductor parts and 451 and 1000 cycles for manufacturer A and B, except for 1 unit of 5 from manufacturer B. Device No. 48 from manufacturer B failed 1 A test between cycle 195 and 451, was sent to RGA analysis, and was found to suffer a moisture content of

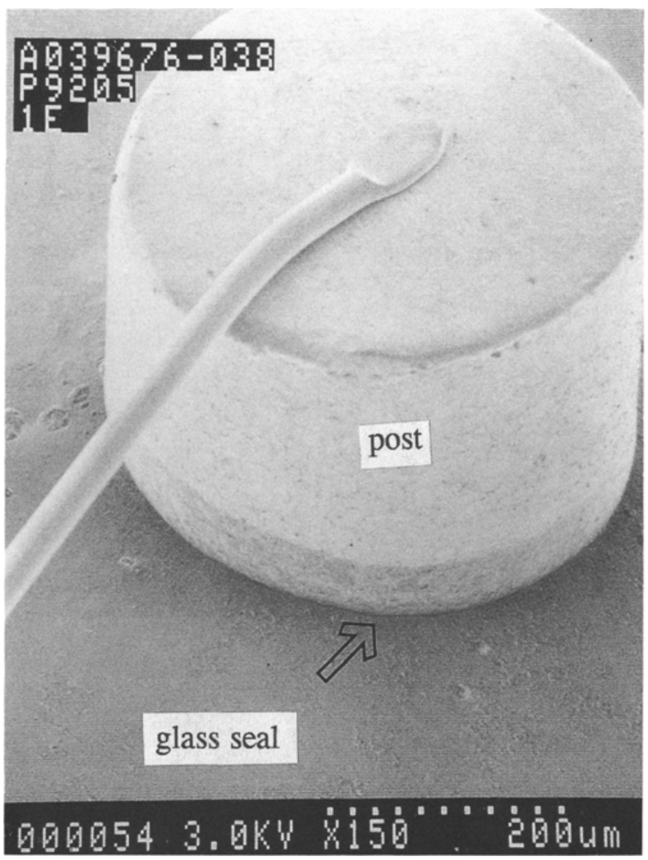

Fig. 2 "Ring" of residue from package manufacture on post. 150×

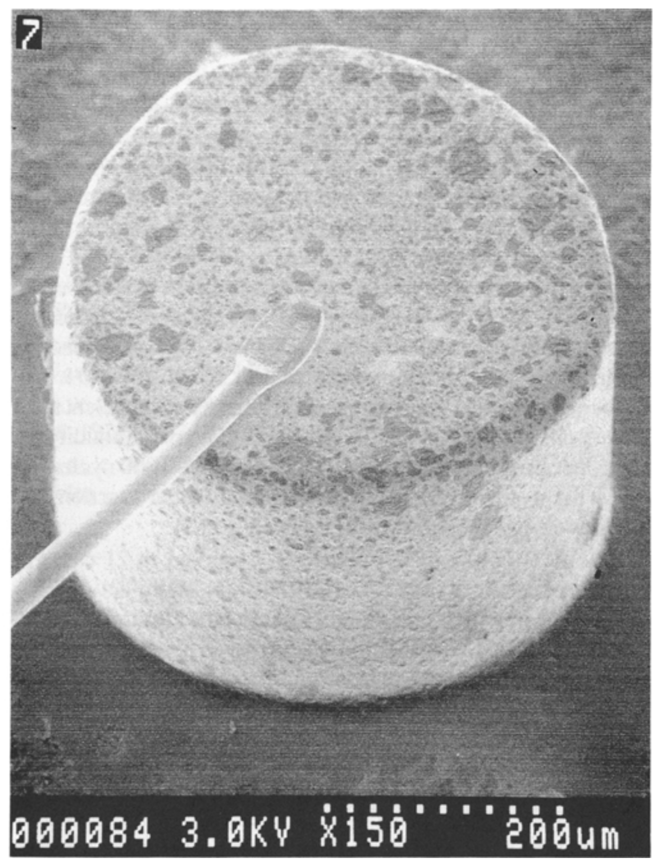

Fig. 3 Corrosion-free post after 1000 h –65 to +175 °C temperature cycles. 150×

2.35%. A SEM photo of the die pad corrosion is shown in Fig. 4 and 5. EDX showed the corrosion product to be $AlCl_3$. The posts showed no evidence of wire-to-post bond corrosion.

2.1.2 VF_{beo}

This is the automatic version of the VF_{beo} (one amp) test above. It records the voltage at 1 A. The tester rises to 1A in approximately 5 µs, dwells for 380 µs, then falls in approximately 5 µs. All parts were quite stable as shown in Table 1.

2.1.3 BV_{ceo}

This automatic test reverse biases the base-collector junction through the emitter, base open. The tester rises to 5 mA in approximately 5 µs, dwells for 380 µs, then falls in approximately 5 µs. One device in 50 Raytheon Semiconductor devices, No. 14, failed 100 µA BV_{ceo}. It suffered BV_{ceo} degradation from 49.4 to 47.8 V between 551 and 1000 cycles. The device had its lid removed and was found to have grown a fine crystalline filamentary species everywhere on the die, especially in the vicinity of the pad bonds. EDX spectra indicates major peaks of O, Si, Na, and traces of Al and P. See SEM

Table 1 Median VF_{beo} measurements from temperature cycling intervals

Manufacturer	Lot	No. of devices	VF_{beo}, V			
			0 cycles	300 cycles	551 cycles	1000 cycles
RSD	1989R-5; Group 1	30	1.49	1.49	1.49	1.49
RSD	1989R-6; Group 2	20	1.55	1.55	1.55	1.56
Manufacturer	**Lot**	**No. of devices**	**BF_{beo}, V**			
			195 cycles	**451 cycles**	**1000 Cycles**	
A	1991A-1	5	1.44	1.44	1.44	
A	1991A-2	5	1.49	1.49	1.49	
A	1992A-3	5	1.42	1.43	1.45	
B	19XX-1	5	1.40	1.40	1.41	

Note: RSD is Raytheon Semiconductor. A is manufacturer A. B is manufacturer B.

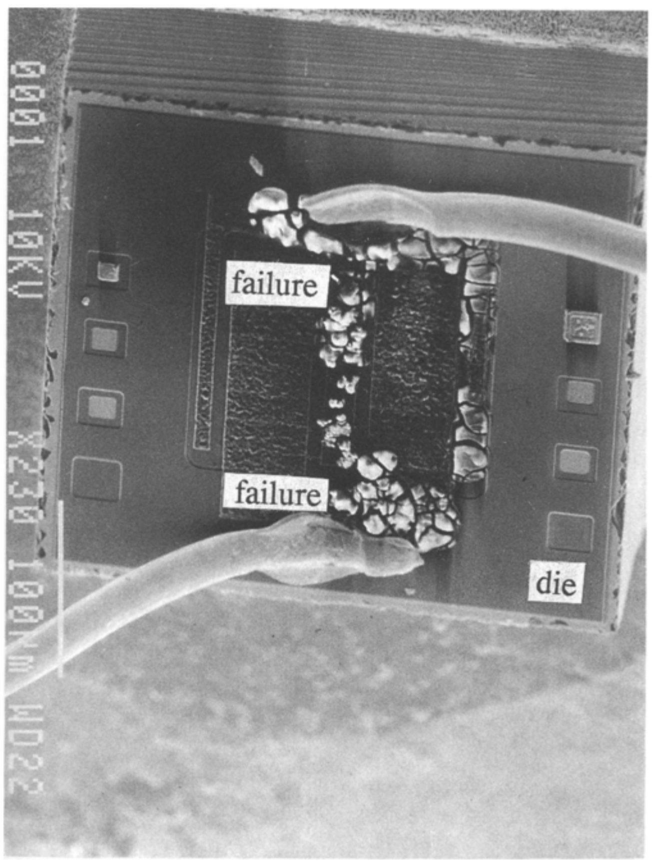

Fig. 4 Wire-to-die failure after 451 h −65 to +175 °C temperature cycles. 230×

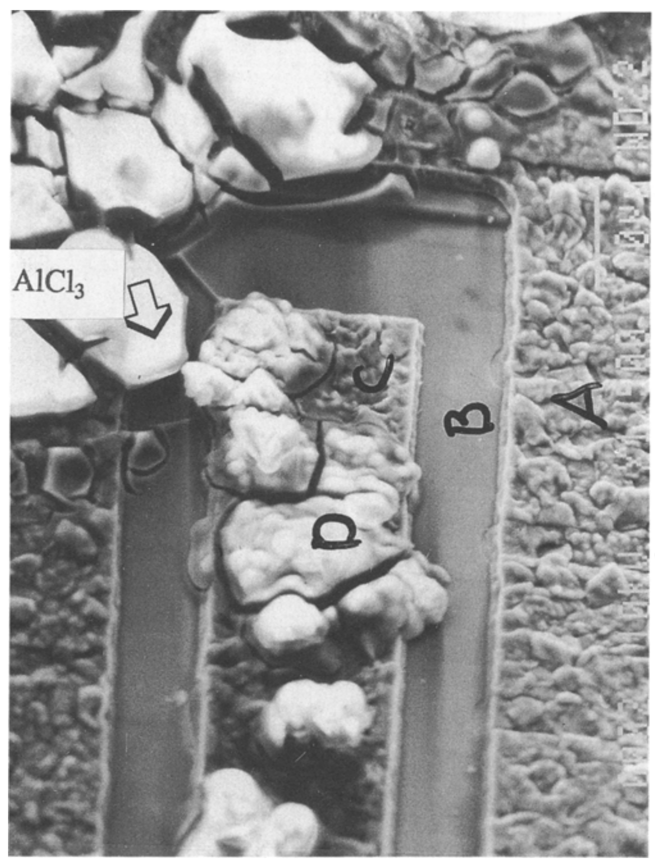

Fig. 5 Close-up view of aluminum chloride corrosion of Fig. 4 identified by EDX. 1500×

photo, Fig. 6 and 7. However, there was no evidence of wire-to-post bond degradation.

The otherwise stable parts are summarized in Table 2.

2.1.4 Test Results

No wire-to-post bond corrosion occurred in any sealed cans after 1000 temperature cycles even in the presence of moisture exceeding 5000 ppm in some of the test devices, indicating the robustness of the fundamental process.

2.2 *Temperature and Humidity Stress: 85 °C/85% RH*

The intent was to grossly accelerate corrosion of wire-to-post bonds with (a) effectively unlimited moisture ambient air and (b) high temperature. At various intervals, the resulting corrosion materials were analyzed. The devices had their lids removed and were then submitted to 85 °C/85% RH ambient air for extended time periods to accelerate any corrosion mechanisms. Auger, SEM, and EDX data were obtained after 20, 40, 55.5, 66, and 370 h. Standard 2N5109 devices from various date codes were used: Raytheon Semiconductor, 1988R-7, 1992R-3, 1992R-8, 1991R-9, and 1991R-10; manu-

Table 2 BV_{ceo} measurements during temperature cycling

Manufacturer	Lot	No. of devices	BV_{ceo}, V 0 cycles	300 cycles	551 cycles	1000 cycles
RSD	1989R-5; Group 1	30	60.7	60.7	60.7	60.6
RSD	1989R-6; Group 2	20	51.8	51.8	51.8	51.7
Manufacturer	**Lot**	**No. of devices**	**BV_{ceo}, V 0 cycles**	**195 cycles**	**451 cycles**	**1000 cycles**
A	1991A-1	5	41.5	41.8	41.8	41.8
A	1991A-2	5	40.6	40.7	40.7	40.8
A	1992A-3	5	33.0	33.0	32.9	33.0
B	19XX-1	5	46.9	47.3	47.5	47.7

Note: RSD is Raytheon Semiconductor. A is manufacturer A. B is manufacturer B.

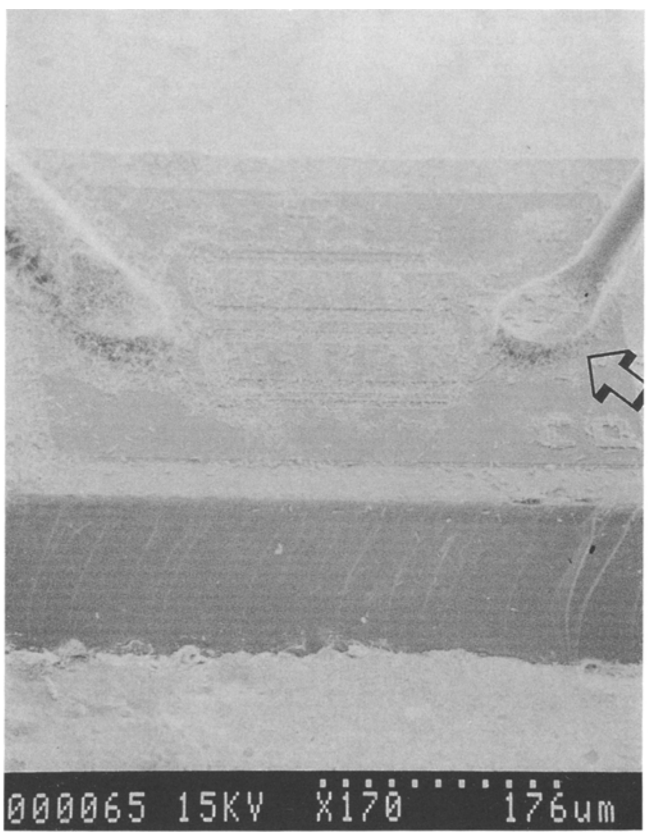

Fig. 6 BV_{ceo} drift after 1000 h −65 to +175 °C temperature cycles. 170×

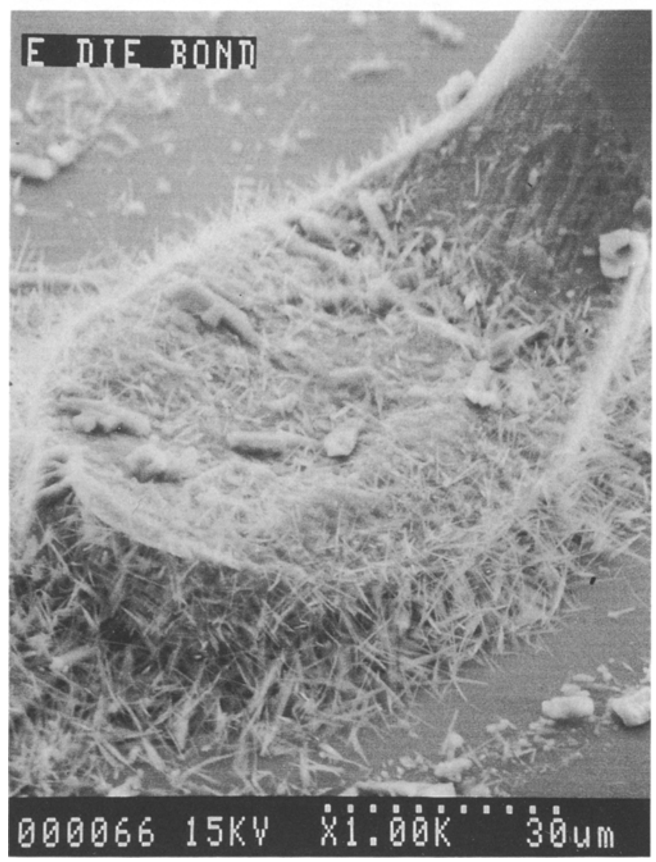

Fig. 7 Close-up view of filamentary growth of Fig. 6. 1000×

facturer A, 1991A-1, 1991A-2, 1992A-3, and 1992A-4, and manufacturer B, 19XXB-1.

The degree of acceleration from the 85 °C/85% RH test method cannot be easily estimated. As reported in the literature (Ref 2), temperature and relative humidity have opposing results in sealed environments. An approximate estimate can be developed from the humidity and temperature acceleration tables that provide a humidity acceleration factor of 75× from 20.3 to 85% RH and a temperature acceleration from 35 to 85 °C of 1000× (see Fig. 8) for a combined acceleration factor of 7500×.

Table 3 Auger and EDX results of anomalous appearing materials for various test points

Vendor	Lot	Hours	O	C	Al	Fe	Cl	Ca	Au	Ni	K	Si	S	Na	P	Pb	Mg
Raw	...	0					t		x								
C	1988R-7	0	x	x			t		x	t	t	x					
C	1992R-3	0	x	t	x		t			x	t	x					
C	1992R-8	0	x	x			t			x	t	x	t	t			
C	1991R-9	0	x	x						x		x					
A	1992A-4	0								x					x		
A	1992A-4	40	x		x	x	x			x		x			x		
C	1992R-3	40	x		x					x	x	x		t	t		
A	1992A-3	66	x		x					x	t	x			x		
B	19XXB-1	66	x					x	x	x		x		t			
C	1988R-7	370	x		x	x				x		x				x	
A	1992A-4	370	x		x	x									x	x	t
C	1991R-9	370	x			x	t								x	x	x
C	1992R-3	370			x	x				x		x				x	
C	1991R-10	370	x		x	x						x				x	

Note: A is manufacturer A. B is manufacturer B. C is Raytheon Semiconductor. x is major peak. t is trace.

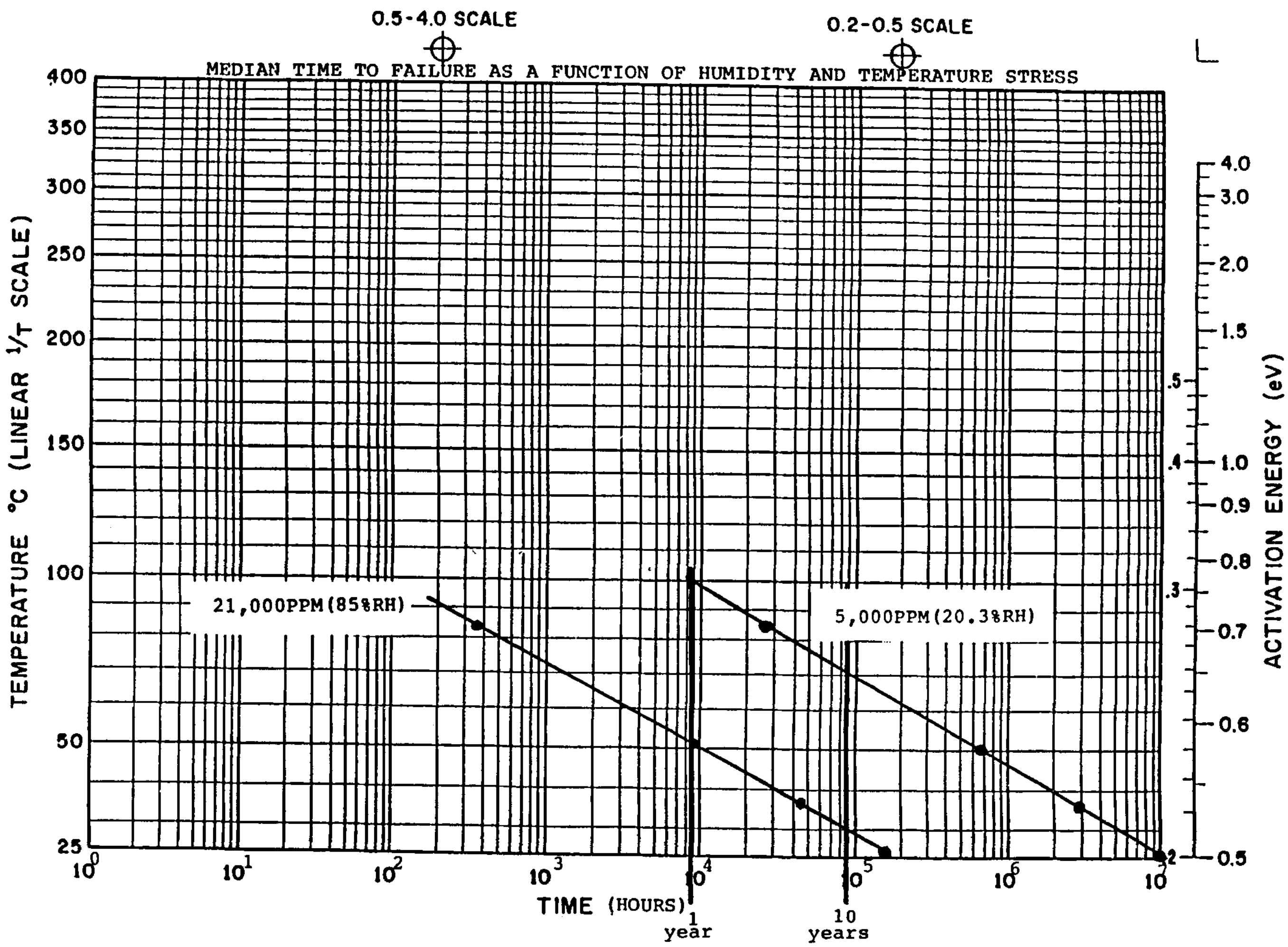

Fig. 8 Estimated acceleration under temperature and humidity

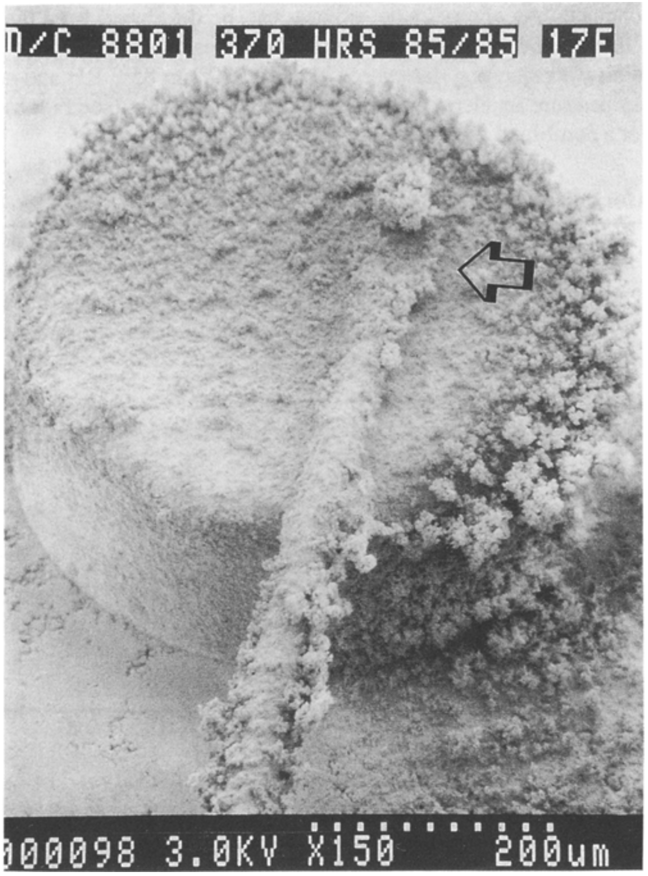

Fig. 9 Good electrical contact of wire-to-post after 370 h of exposed 85 °C/85% RH. 150×

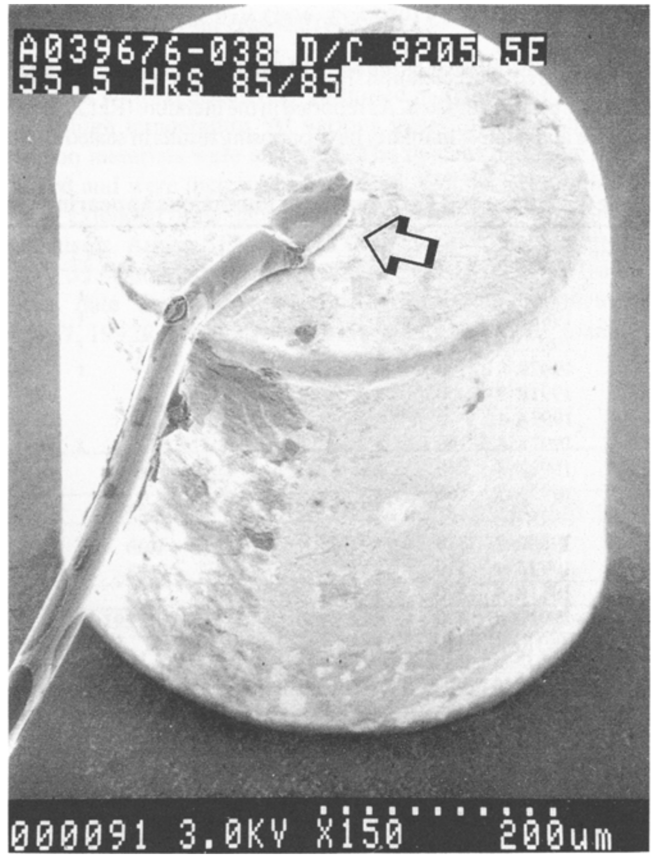

Fig. 10 Good electrical contact of wire-to-post after 55.5 h of exposed 85 °C/85% RH. 150×

2.2.1 Test Results

Most devices did not corrode into an open circuit even after 370 h. (See Fig. 9.) Visually, both Raytheon Semiconductor and manufacturer A suffered significant corrosion after 370 h, and the test was terminated at that point. However, only manufacturer A suffered a failure at 20 h. Electrically, some leads were open circuits after 370 h for all manufacturers, but not because of corrosion of the aluminum wire-to-post bond.

Progressive corrosion was noted in the sequential SEM photos of Ni- and Au-plated posts shown in Fig. 10 and 11 for all manufacturers' parts. Corrosion composed largely of $AlCl_3$ was observed in Raytheon Semiconductor parts 1988R-7, 1992R-8, and 1992R-3 and manufacturer A parts 1992A-4 at 20 h. at 40, 55.5, and 66 h, no appreciable change was noted. Massive post bond corrosion was not observed until 370 h. This failure appearance is not typical of the previously noted field failure characteristics. (See comparative field failure photos, Fig. 1.)

Table 3 shows Auger and EDX major peaks and trace elements.

A Ni-plated manufacturer A package suffered catastrophic failure after 20 h due to wire-to-post bond corrosion. This is believed to be attributable to H_3PO_4, a residual from the electroless plating process. No initial corrosion was observed.

Staining of the post plating observed in Raytheon Semiconductor lots 1992R-2 and 1992R-3 and manufacturer A lots 1991A-1, 1991A-2, and 1992A-3 increased monotonically.

The sudden appearance of a crystalline species of lead (Pb) at 370 h is probably attributable to migration of solder lead from the wires outside the package. EDX of the glass seal on a freshly opened can from Raytheon Semiconductor 1989R-1 shows no trace of Pb, which might otherwise have leached from the glass. The glass analysis instead showed a barium silicate formulation.

2.3 *Chlorine Bake Test*

In an additional experiment, Raytheon Semiconductor TO-39 package headers, known to be highly contaminated with chlorine, were sealed in ambient air. 650 devices were subjected to high-temperature storage baking and thermal cycling. One catastrophic electrical failure occurred after 300 cycles. The test continued to 800 cycles with no additional failures.

3. Conclusions

- Raytheon Semiconductor end user returns data indicate a field failure rate of open transistors in To packages of 0.21 ppm defective, demonstrating generally humidity resistant, robust devices.

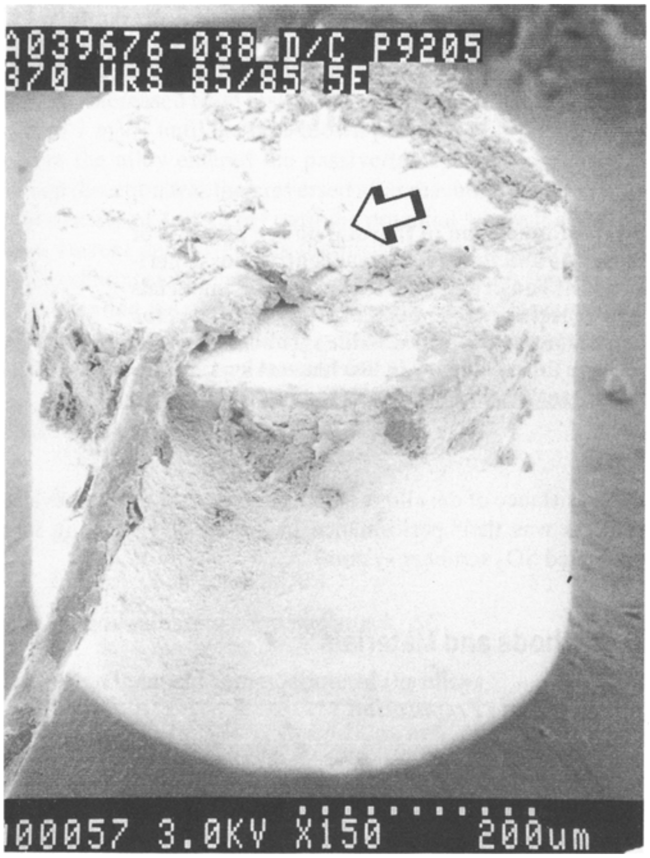

Fig. 11 Good electrical contact after 370 h of 85 °C/85% RH in same package as Fig. 10. 150 ×

- The low field failure rates preclude both inspection screening and total avoidance of random contaminants, which probably contributes to the failure mechanism. Moisture content can be minimized during assembly processing.
- Known wet parts with factors of 3 or 4 higher than the MIL-STD limit of 5000 ppm (0.5%) remain solidly functional. No corrosion occurs even after 1000 temperature cycles.
- When the 370 h of actual test conditions are corrected by the temperature and humidity accelerations, a lifetime of 370 h × 75 × 100 = 2,775,000 h, or 316.8 years at 5000 ppm maximum moisture content and 35 °C ambient air can be calculated. Sealed cans would be expected to stop corroding as available reactant species are depleted.

Acknowledgments

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