

Plastic Encapsulant Impact on Au/Al Ball Bond Intermetallic Life

The impact of high temperature storage on Au/Al ball bonds for integrated circuits is well documented in the semiconductor industry. With time and temperature the Au/Al intermetallics advance to the Kirkendall voids (3.1) resulting in a ball bond lift failure mechanism. With hermetic devices and non-flame retarded epoxy encapsulated devices this failure mode typically did not present itself as a reliability issue since device application temperatures were such that this failure mode did not occur within the 100K hour reliability requirement. Since the introduction of halogenated resin flame retardants and synergistic halogenated resin/antimony oxide flame retardants into epoxy encapsulants in the mid-1970s, numerous investigators have determined that these flame retardants degrade the integrity of the Au/Al intermetallics which results in accelerated advancement to the Kirkendall voids (bond failure).

References:

E. Philofsky, "Intermetallic Formation in Gold-Aluminum Systems," Solid State Electronics, p. 1391, 1970

R.C. Blish, II, "Wire Bond Integrity Test Chip," *International Reliability Physics Symposium*, p. 142, 1983

R.J. Gale, "Epoxy Degradation Induced Au-Al Intermetallic Void Formation in Plastic Encapsulated MOS Memories," *International Reliability Physics Symposium*, p.37, 1984

M. Khan, "Effect of High Thermal Stability Mold Material on the Gold-Aluminum Bond Reliability in Epoxy Encapsulated VLSI Devices," *International Reliability Physics Symposium*, p. 40, 1988

A.A. Gallo, "Effect of Mold Compound Components on Moisture Induced Degradation of Gold-Aluminum Bonds in Epoxy Encapsulated Devices," *International Reliability Physics Symposium*, 1990

Example Of Bake Study And Data Analysis

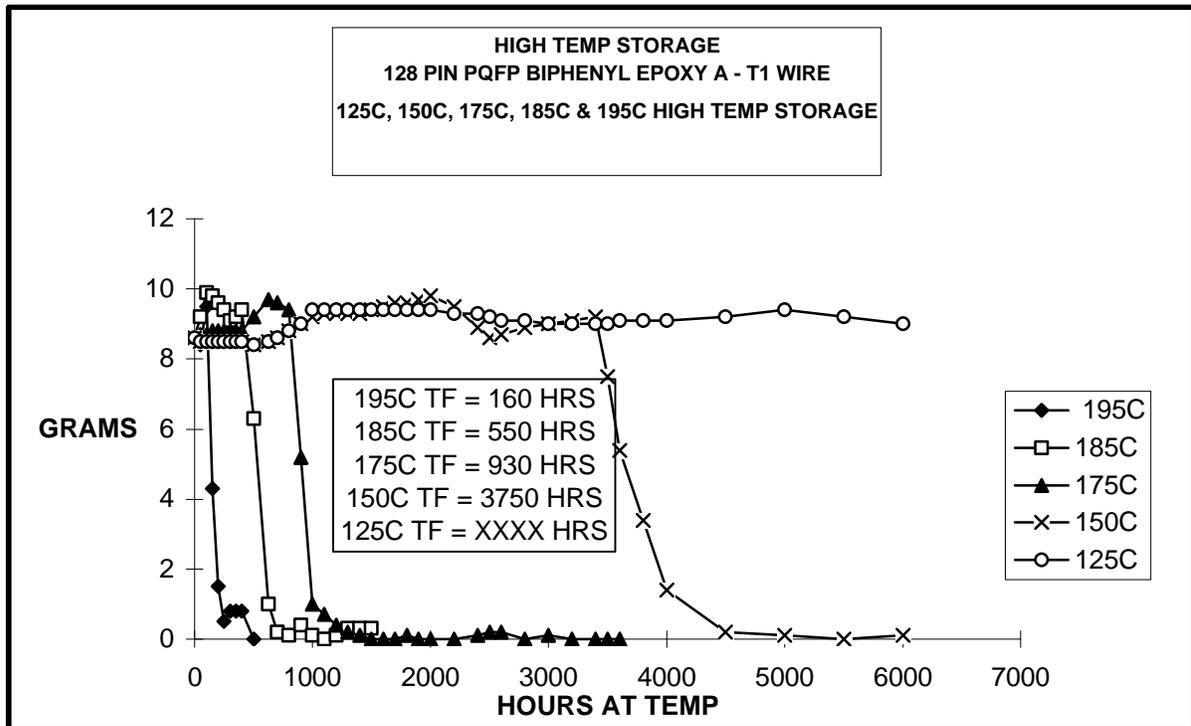
The time-to-failure (Tf) due to excessive intermetallic development at a given storage temperature is defined as the time for the MODE 1 failure value to decrease to 4.0 grams. The Tf for each temperature can be determined from data like that in Table 1 by interpolating the time when the wire pull value decreases to 4.0 grams. The interpolated Tf for 195C, 185C and 175C are 160 hours, 550 hours and 930 hours, respectively.

Onset of Failure Minimum Mode 1 (Bond Lift) Failure Values - Includes Interpolated Values for Charting															
STORAGE TEMP	WIRE PULL IN GRAMS AFTER HIGH TEMP STORAGE IN HOURS *														
	0	50	100	150	200	250	300	350	400	500	625	700	800	900	1000
195C	8.6	8.4	9.5	4.3	1.5	0.5	0.8	0.8	0.8	0					
185C	8.6	<u>9.2</u>	9.9	<u>9.8</u>	9.6	<u>9.4</u>	9.1	<u>9.2</u>	9.4	6.3	1	0.2	0.1	0.4	0.1
175C	8.6	<u>8.7</u>	<u>8.7</u>	<u>8.8</u>	8.8	<u>8.8</u>	<u>8.8</u>	<u>8.8</u>	8.8	<u>9.2</u>	9.7	<u>9.6</u>	9.4	5.2	1
150C	8.6	<u>8.5</u>	8.4	<u>8.5</u>	<u>8.6</u>	<u>8.8</u>	<u>9</u>	9.2							
125C	8.6	<u>8.5</u>	8.4	<u>8.5</u>	<u>8.6</u>	<u>8.8</u>	<u>9</u>	9.4							

* Average wire pull value for the population at that read interval
 * **Minimum MODE 1 value at that read interval**
 * Interpolated value

The data can be displayed graphically as shown. To plot the data for all five temperatures on the same chart it is necessary that the table 1 includes the interpolated values for read intervals taken at one temperature but not taken at other temperatures.

Wire Pull Versus Time at Temperatures of 195C, 185C, 175C, 150C and 125C



Prediction of Intermetallic Life at Application Temperatures - The Arrhenius Approach

The Arrhenius equation indicates that the rate constant (k) for a given process is an exponential function of the temperature.

$$k = Ae^{-(E_a/K_b)T}$$

where A is a pre-exponential factor, E_a is the activation energy (eV) for the reaction, K_b is the Boltzman's constant (0.0000861 eV/°K) and T is the temperature in degrees Kelvin (°K = °C + 273).

The acceleration factor (AF) achieved by changing the temperature from T_1 to T_2 will be a ratio of the rate constants for the two temperatures.

$$AF = \frac{k_1}{k_2} = \frac{Ae^{-(E_a/K_b)T_1}}{Ae^{-(E_a/K_b)T_2}} = e^{(E_a/K_b)(1/T_2 - 1/T_1)}$$

Knowing the acceleration factor between two temperatures, one can determine the activation energy for the rate limiting step for the reaction occurring at the two temperatures.

$$\ln(AF) = \frac{E_a(1/T_2 - 1/T_1)}{K_b} \quad E_a = \frac{K_b \ln(AF)}{(1/T_2 - 1/T_1)}$$

Applying the Arrhenius Approach to the Wire Pull or Ball Shear Results

If tf_1 is the time-to-fail the 4.0 grams (20 grams-force) limit at temperature T_1 , then $1/tf_1$ represents the rate of failure to the 4.0 gram (20 grams-force) limit. Therefore,

$$k_1 \propto 1/tf_1 \quad k_2 \propto 1/tf_2$$

and,
$$AF = \frac{k_1}{k_2} = \frac{tf_2}{tf_1}$$

Using the time-to-failure data the acceleration factor between the respective temperatures are follows:

$$AF \text{ from } 185C \text{ to } 195C = \frac{550 \text{ hours}}{160 \text{ hours}} = 3.44$$

$$AF \text{ from } 175C \text{ to } 185C = \frac{930 \text{ hours}}{550 \text{ hours}} = 1.69$$

$$AF \text{ from } 150C \text{ to } 175C = \frac{3750 \text{ hours}}{930 \text{ hours}} = 4.03$$

Knowing the acceleration factors between two temperatures, one can determine the activation energy (E_a) between those temperatures by using the following equation.

$$E_a = \frac{K_b \ln(AF)}{(1/T_2 - 1/T_1)}$$

Therefore, between 150C and 175C the activation energy would be 0.91 eV. If the reaction mechanism or rate limiting step in the reaction mechanism is the same over a wide temperature range, then we could use the 150C/175C activation energy of 0.91 eV for calculating/predicting the time-to-failure at higher temperatures and at lower temperatures. For instance, if we want to predict the time-to-failure at 125C, then we would calculate the acceleration factor between 125C and 150C using the following equation.

$$AF = e^{\frac{E_a}{K_b} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)}$$

In this case, the AF between 125C and 150C is 4.80. Multiplying the tf at 150C (3750 hours) by this AF we get the tf at 125C in hours (18000 hours). If the tf at 125C is divided by 8760 hours (number of hours in one year), then we get the tf at 125C in years (2.0 years).

Because of the potential for error that the activation energy based on a two point (two temperatures) method can introduce into these calculations, the accepted procedure is to generate tf's at 3 or 4 temperatures, plot ln(1/tf) versus 1/T and calculate the activation energy from the slope of the plot.

$$\ln\left(\frac{1}{tf}\right) = \frac{-E_a}{K_b T} \quad \text{T is temperature in } ^\circ\text{K; slope} = \frac{E_a}{K_b}$$

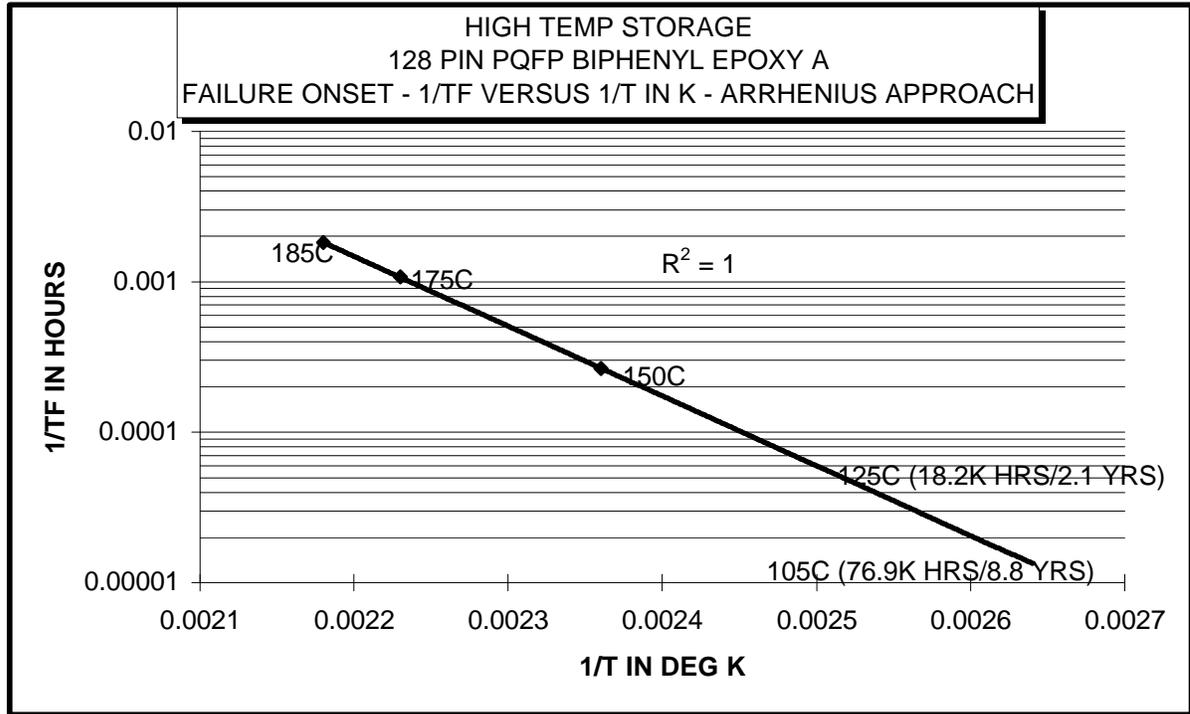
Even when using the 3 or 4 point method for determining the activation energy one must exercise some judgment on whether this technique will provide the most accurate results. If the data series in the ln(1/tf) versus 1/T plot clearly indicates a linearity, then the 3 or 4 point method will provide the most accurate value for the activation energy and the most reliable predictions on intermetallic life at application temperatures. If, however, the data series in the ln(1/tf) versus 1/T plot indicates a definite curvature trend (activation energy is increasing or decreasing with temperature), then one is probably better off using the 2 point method where the activation energy is calculated from the two temperatures that are closest to the application junction temperatures.

Intermetallic Life Predictions Based on a Regression Treatment of the Arrhenius Approach

Once the tf's have been determined for the temperatures being evaluated a time-to-failures versus temperature table can be created similar to that shown below

STORAGE TEMP	tf in HRS	1/T in °K	1/tf
150	3750	0.00236	0.000267
175	930	0.00223	0.001075
185	550	0.00218	0.001818
195	160	0.00214	0.00625

Extended Trendline and Projections for Intermetallic Life at 125C and 105C



The example used in the above intermetallic life predictions shows the importance of having sufficient data points to establish what the reaction or mechanism trend is as the temperature decreases. Without the 150C data point, we could not have established the linear trend below 185C and would not have had a case for deleting the 195C data point. Therefore, in order to achieve accuracy in the intermetallic life predictions 4 to 5 temperatures should be used in these evaluations so that the trend at lower temperatures can be estimated with reasonable confidence.