Humidity Accelerations for Testing Standards

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Summary *Accelerated humidity test data on plastic ICs are analysed, showing higher thermal acceleration and longer life for modern components compared to older ones. Accelerations for total test time in humidity are given, and the effect of assumed moisture ingress time through the plastic is also treated. A procedure for formal qualification of moisture life is proposed.*

Keywords: Moisture, Humidity, Corrosion, Acceleration Factors, Testing

1 Introduction

The introduction of epoxy molded encapsulations for semiconductor devices, to replace the more costly hermetic packages, brought with it the introduction of the failure mechanism of metallization corrosion as a major concern. These failures occur because of the diffusion of humidity through the epoxy, or along the lead frame, increasing the surface conductivity of the insulator between adjacent metal lines under bias, contributing to corrosion and failure. The failure distributions are a function of the bias, temperature, contamination and relative humidity at the insulator surface. The relationships of time to failure and the temperature and humidity have been the subject of much testing effort.

Until recently, each study of these relationships was limited to a few tests run in a single laboratory, comparing life under special test conditions to the life at 85°C and 85%RH (85/85), which has been the standard test condition for many years.

This paper is a revised summary of a study, published 1991, ref [1], that was based on a large number of tests, looking for an overall relationship not limited by small numbers of tests which individually may lead to widely different relationships.

2 Background

In 1986, a paper [2] was presented at the International Reliability Physics Syposium which used 61 points from the published humidity acceleration data available to the author.

Since the same electrical bias conditions were held through each study, the humidity acceleration ratios normalise the effects of test-to-test variations in bias, device structure or contamination level.

A common relationship was found to be optimum for stresses both higher and lower than the reference (85/85) from 158°C down to 50°C and from 100%RH down to 50%RH, the range of the available data. The formula has the form:

$$t_f = A(\%RH)^n exp(\frac{Ea}{kT}) \qquad ....(1)$$

Where A is a constant, $n = -2.66$, $E_a = 0.79$ eV and k= Boltzmanns's Constant, $8.615*10^{-5}$ eV/K

This relationship points to one or more of several possibilities:

- Short tests for product acceptance, with more frequent testing, and less interference with shipment schedules.
- Increasing the test time to the equivalent of several thousand hours at 85/85, consistent with the availability of better epoxies, and possibly proving the reliability level needed for general military and telecom usage.
- For applications in general, the prediction of moisture failure rates in application environments.

3 Current data

The data used in this current analysis is taken from publications from 1979 to 1987 [1], using a total of 82 data points of comparisons of the ratio Ro of $t_m(T/RH)$ to $t_m(85/85)$ to the calculated ratio Rc according to an assumed formula.

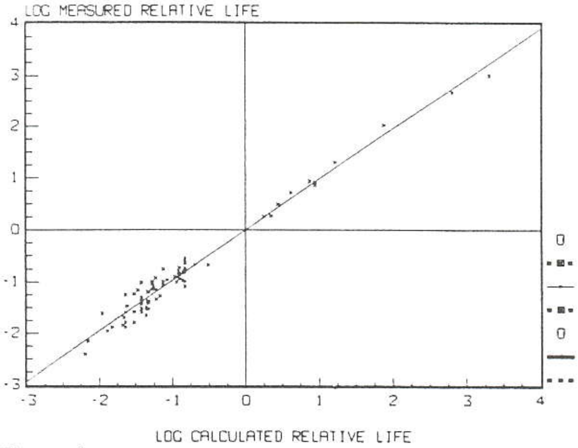

Figure 1
Correlation diagram over calculated and measured relative lives in moisture tests

Figure 1 shows the plot of all Ro vs Rc points, as in Ref. [2], but resulting from the range of data from 158°C down to 20°C and from 100%RH down to 20%RH. The data optimally fit equation (1) with the following parameters:

n= -3.0; Ea= 0.9 eV

Extreme points taken from data at 85/20 and 20/58 conditions were from unencapsulated devices [3], but the Ro/Rc ratios were well scattered in the distribution from all the data.

Using new parameters, the equation for relative life at T/RH to that at 85/85 can be written as:

$$Rellife= \frac{85^3}{RH^3} exp(\frac{0.9eV}{k}(\frac{1}{T+273} - \frac{1}{358})) \qquad ...(2)$$

This is written as "Relative life" because it amounts to a Deceleration Factor from higher stress to 85/85 and an Acceleration Factor of 85/85 over a lower stress condition.

Figure 2 shows average activation energies from all tests versus median life at 85/85. An average value for long lived products seems to be 0.9 eV.

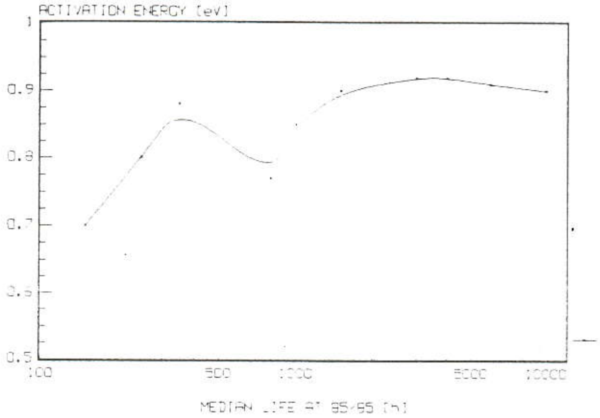

Figure 2

Average activation energy in moisture tests versus median life at 85/85

Gustafsson and Lindborg [4] show that a failure percentage of 2500h exposure at 85/85 drops linearly from 60% at a chlorine content of 70ppm to essentially 0% at 0ppm. This is such a significant change, as is the reduction in ppm chlorine in epoxy since about 1979, that it may well mask any other changes in quality during that period.

The data processing was carried out on those tests only having t_m (85/85) greater than 1000h or 3000h, with the following results:

Table 1. Regression analysis vs median life

Data	SS	Intercept	Slope	Corr. coef
All data	82	1,010	0,978	0,985
t_m> 1kh	58	1,031	0,993	0,985
t_m> 3kh	37	1,123	0,992	0,993

The improved correlation coefficient for longer-lived product indicates that the model is useful for modern and future products.

4 Comparison with other models

The data material has been used to see how well it fits with different published models. Table 2 shows the result for the following models.

LAWSON: A= $\exp(0.6/kT-0.00044[RH]^2)$
EYRING: A= $\exp(0.65/kT+ 304/RH)$
REICH-H: A= $\exp(-0.073(T[^\circ C]+ RH[\%])$
S-K: A= 10^ (0.41/kT-18.69RH/T+ 0.00819RH)
PECK-H: A= $\exp(0.9/kT)*[RH]^{-3}$
KLINGER: A_r= $\{(100-RH)/RH\}^m$
(Humidity acc. only; assume 0,9 eV and m= 1)

It is important to note that the models differ rather much at low humidity stress. This is shown in figure 3 that plots relative lives vs RH at a constant temperature. Also note that the model given by Klinger [5] based on theoretical considerations fits reasonably well to the empirical RH^{-3} model within the normal RH-range of interest, 30-90%.

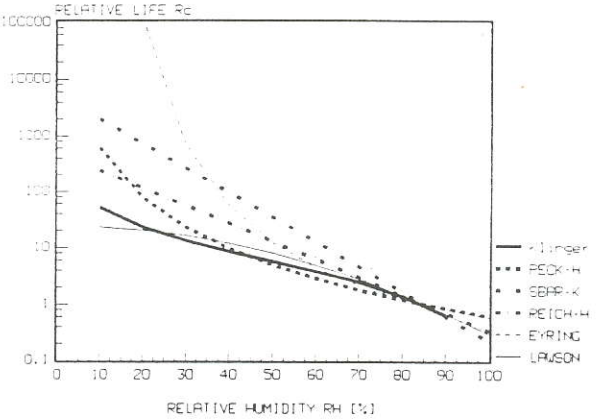

Figure 3

Relative lives versus RH according to different published models normalised at 85% RH

Table 2. Regression analysis using different models

MODEL	Intercept	Slope	Corr coeff
LAWSON	0,74	1,31	0,959
EYRING	1,26	1,42	0,958
REICH-H	1,05	1,00	0,974
SBAR-K	0,48	1,04	0,934
PECK-H	1,01	0,98	0,985
KLINGER (for m= 1)	0,95	0,99	0,956

5 Moisture ingress time

Many observations have indicated that a length of time is required for moisture to get from outside the plastic encapsulation to the chip surface, in order to start the corrosion process. If such a time can be determined as a function of the condition of stress, and subtracted from the total time to failure, a more precise determination of the corrosion parameters alone might be obtainable.

Figure 4 shows calculated moisture density increase at the chip surface within a PDIP as a function of time and temperature.

With the exception of particularly short-life ICs, it can be assumed that moisture reaches the chip surface by means of diffusion through the epoxy from the exterior surface. This is driven by the partial pressure of ambient water vapor. The moisture density follows the equation corresponding to an infinite supply of moisture at the surface:

$$\rho(t,x)=\frac{4}{\pi}(\rho f-\rho i)\Sigma\frac{1}{n}exp(-D(\frac{n\pi}{2h})^{2}t)\sin(\frac{n\pi x}{2h})+\rho i$$

n= 1,3,5 ...

where ρ_f = Final moisture density , ρi = Initial moisture density, h = Thickness of plastic over die
x = Distance from the surface of the package
D= Diffusivity of water in the epoxy and t = Time since start of exposure

Many simulations were performed on the data to use a range of delay times, consistent for each test condition, in order to isolate the "corrosion time" from the total observed test time. In every case, the correlation coefficient of the resulting "corrosion time" was degraded from that for the total test time.

As a result it is concluded that with present product, the total test time gives the best statistical representation of the product for life extrapolation to any other environmental condition.

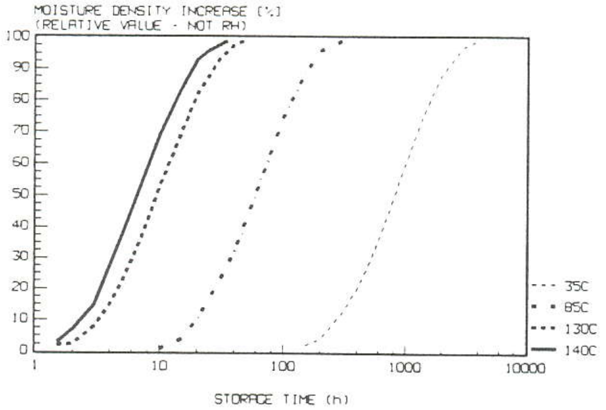

Figure 4
Moisture density increase at the die surface as a percentage of the final static increase of moisture absorption relative to initial conditions

6 Application of results

The median life required at a test stress is determined in the following formal way:

- Determine the expected operating life, the maximum failure rate and the average field use condition T/RH
- Establish a median life for the components, t_m, to provide a failure rate that is below the maximum allowed within expected operating life.
- Establish a life testing requirement to ensure a life that is long enough in the application using a low percentage of the allowable failures to control the critical part of the distribution.

This procedure is simplified by the fact that all humidity tests on at least recent products have shown a typical standard deviation (s) range from 0.25 to 0.5 (as the natural logarithm of the ratio of the t_m to $t_{.16}$). The effect of this "tight" distribution is that the failure rate does not gradually rise to its maximum value but is quite low until time approaches $0.1t_m$, when it goes up very rapidly.

In the case that there is a power dissipation during field use the humidity density will decrease at the chip surface. The reduced water density close to the chip may be modelled as an effective RH_c if the surrounding RH in the test chamber is RH_T and the chip heating is PR_{th}

$$RH_c= RH_T exp(5235(\frac{1}{273+T+PR_{th}}-\frac{1}{273+T})) \quad .(4)$$

A temperature rise of 10 °C in field use may reduce the necessary test time by a factor of two if the test can be run at low power dissipation.

7 Life test time

If the life requirement is 40 years, 10 fits will be obtained at 40 years if the median life, t_m , is 200 years. 100 fits will be reached if t_m is only 120 years, ref [6]. An application of 35°C/60%RH for 200 years time is equivalent to 5411h at 85/85. With further acceleration into the HAST testing region, the t_m requirements are as in Table 3, all assuming s = 0.5

Table 3. Median life in HAST test to simulate 40 years with wear-out failure rate less than 10 fits

Test cond. (T/RH)	Median life (h)
130/85	218
130/90	184
140/85	116
140/90	98

With an s = 0.5 the time to 5% failures is down from the t_m by a factor of 2.3, so the test time for that requirement could be 43h at 140/90 testing. Table 4 gives test times necessary to verify different failure rates due to humidity with a sample of 77/1. Failure rates at both 40 and 25 years are also plotted in Fig 5.

Table 4. Minimum test time necessary to assure less-than-specified wear-out failure rates at 35/60.

Fits	**@40yr**	**@25yr**	**@40yr**	**@25yr**
. **Test**	**85/85**	**85/85**	**130/85**	**130/85**
300	1327	895	51	35
100	1698	1142	65	44
30	2099	1451	81	56
10	2469	1667	95	64

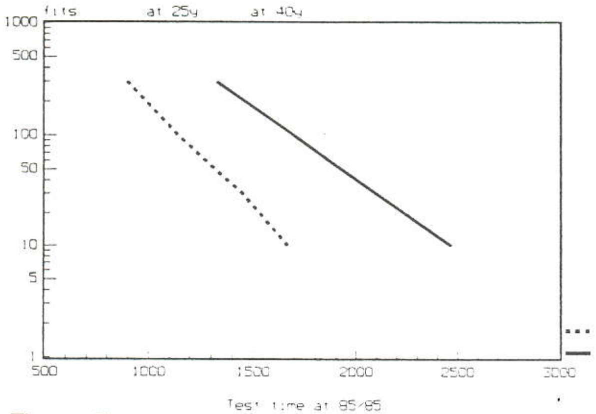

Figure 5

Maximum wear-out failure rate at 40 and 25 years vs survival time at 85/85 (LTPD= 5%)

8 Early failure levels

A quality monitoring procedure generally calls for a short test that can be performed within a few days or even shorter. Failures that are found in this test represent early failures and give information on assembly process quality, especially related to the adherence between plastic and the die or the quality of the glassivation layer. As the moisture diffusion time to the die may be in the order of 24h for a dual-in-line package one should not normally expect corrosion during the test.

A moisture test that might be regarded as non-destructive should not be longer than about half the time to reach 50 per cent of saturation, say 12h for a HAST test at 130/85.

A quality monitoring procedure could be a weekly HAST test at 130/85/B for 48h on 76 units. If no failures are found this corresponds to an LTPD of 3%. As the time passes the early failure level will soon be quantified. At the same time the test also demonstrates 25 years of use with less than 100 fits, see Table 4.

9 Conclusions

1. HAST testing should replace the present 85/85 testing, in order to reduce testing time and improve feedback.

2. Moisture life extrapolation to T[°C] and RH [%] from 85/85 can be done by:

$$A= [85/RH]^3 * \exp(10444(1/(T+ 273)-1/358))$$

3. The moisture ingress time has been calculated for a PDIP. The delay should be considered when evaluating very short HAST tests.

4. The life of ICs made with high standards of cleanliness and epoxy purity, as now available, seems to be long enough for most indoor applications.

5. Standard sample sizes and minimum $t_{5\%}$ test times have been provided for long-life telecom use for the case of an average use condition of 35 °C and 60% RH, ref [7, 8]

6. Components heated 10 °C by power dissipation in field use will be of minor concern regarding corrosion in normal telecom ambient.

10 References

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