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OPTIMAL ACCELERATION OF CYCLIC THB TESTS FOR PLASTIC-PACKAGED DEVICES

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Abstract

We develop a model which can be used to calculate the effective acceleration of a temperature-humidity-bias (THB) stress which alternates between two environmental conditions. A key element of the model is a one-dimensional mathematical description of the moisture-retention properties of the plastic package. The model can be used to find the duty cycle and period of a cyclic THB stress which maximizes the cycle-averaged THB acceleration. We demonstrate the model by applying it to hypothetical cases in which cyclic bias might be used. The demonstration provides guidelines for application of power cycling for 85/85 and 130/85 HAST stressing. The model requires knowledge of the THB acceleration factor of the die-level failure mechanism as a function of the local temperature, humidity (RH) and bias at the die. We use an experimentally-determined acceleration factor model for moisture penetration through passivation microcracks, which is a mechanism of current interest. For this model Acceleration = Constant • $\exp(-Q/kT)$ • RH^b, where $Q = 0.79$ eV, and $b = 4.64$.

1. Introduction

Acceleration of many moisture-related failure mechanisms requires simultaneous application of temperature, humidity, and bias. For plastic-packaged devices dissipating negligible power, a steady-state temperature/humidity ambient and constant application of bias provides maximum possible acceleration. However, some devices are designed in such a way that application of bias causes power dissipation which raises the temperature of the die above the temperature of the environment of the package. This temperature rise causes a reduction in relative humidity adjacent to the die. Generally, for moisture-related failure mechanisms, the deceleration due to reduced humidity at the die outweighs the acceleration due to the increased die temperature. This causes the acceleration of moisture-related mechanisms to be reduced when power is dissipated.

Ajiki, et al[1] studied a case of appreciable power dissipation and showed that cyclic application of bias can be used to maximize the acceleration. During the "bias-off" part of the cycle the molding compound resaturates with moisture, but no electrical potential is available to drive the mechanism. On the other hand, during the "bias-on" part of the cycle, electrical potential is available to drive the mechanism but the RH is reduced because of a drying out of molding compound surrounding the die. The molding compound does not dry out instantly, so it is possible to cycle the device between the powered and unbiased conditions so that appreciable moisture is retained in the molding compound adjacent to the die. This retained moisture is available during the "on" part of the cycle to drive the failure mechanism. With a judicious choice of period and duty cycle, it is possible to maximize the acceleration.

An objective of this paper is to provide a way to calculate the effective acceleration for a plastic-packaged device cycled between two conditions of power dissipation and/or environmental ambient. Calculation of the effective acceleration using the model developed here requires knowledge of the moisture saturation and diffusion properties of molding compound (published by, for example, Kitano, et al.[2]). Also required is a mathematical model of the acceleration as a function of the local temperature, humidity and bias at the die.

Peck[3], has given a model for acceleration of THB-induced failures as a function of the local environmental conditions at the die. However, his model is a fit to mostly historical aluminum corrosion-related failure data. Advances in molding compound technology have largely eliminated corrosion as a failure mechanism. Today, passivation defect mechanisms dominate. Moisture diffuses through passivation defects, and disrupts transistor stability. Accordingly, we have carried out a THB study to determine an acceleration factor model for a passivation defect failure mechanism. The acceleration factor model so determined has the same form as Peck's model, but with different values for the parameters of the model.

Industry-standard THB test methods[4] specify the use of cycled bias in cases of appreciable power dissipation. The passivation defect acceleration factor model provides us with a realistic description of a failure mechanism likely to be encountered in practice. Use of this model in several case study calculations provides guidelines for the application of the cycled bias test method.

In Section II we develop the theoretical framework for the model, and in Section III we use the model in several case studies. The final section summarizes the main conclusions.

II. Description of Model

Calculation of Relative Humidity at Die Surface During Cyclic T/H Stress

Consider a slab, of thickness l, of molding compound. The molding compound at one side of the slab (at $x = l$) is in equilibrium with ambient water vapor and simulates the external surface of the plastic package. The other surface of the slab (at $x = 0$) is a zero-flux surface simulating the interface between the die and the molding compound. If the slab is thrust into an ambient at temperature T_a, and relative humidity H_a, then the moisture concentration at the external surface instantly becomes C_c (subscript "c" denotes "case"). C_c is related to T_a and H_a (defined as a fraction: $0 < H < 1$), through Henry's law:

$$C_c = P\,S(T_{mc}) = H_a\,P_{sat}(T_a)\,S(T_{mc}) \tag{1}$$

where P is the partial pressure of water vapor in the ambient, $P_{sat}(T_a)$ is what the saturated vapor pressure of water vapor would be at ambient temperature T_a [5], and $S(T_{mc})$ is the water saturation coefficient of the molding compound[2] at the temperature of the molding compound, T_{mc}.

Whenever the die dissipates power, the die temperature, T_j, and the case temperature, T_c, will exceed the ambient temperature T_a, and a (steady state) temperature gradient of $(T_j - T_c)/l$ will exist in the molding compound. For typical plastic packages in still ambients, $(T_j - T_c)/(T_j - T_a)$ is about 1/3. Thus it is a reasonable approximation to ignore the temperature gradient in the molding compound in order to simplify the solution of the moisture diffusion problem and to evaluate all molding compound properties at $T_{mc} = (T_j + T_c)/2$.

If the initial moisture concentration profile through the molding compound over the die is $C(x,0)$, it will evolve in time according to the solution of the diffusion equation given by Crank[6]. If we define dimensionless position and time variables as

$$\epsilon = \frac{x}{l} \tag{2}$$

$$\tau = \frac{Dt}{l^2} \tag{3}$$

where D is the diffusion coefficient of moisture in molding compound[2], and if we impose the boundary conditions

$$\frac{dC(\epsilon,\tau)}{d\epsilon} = 0 \quad \text{for} \quad \epsilon = 0 \text{ and } \tau > 0 \tag{4}$$

$$C(\epsilon=1,\tau) = C_c \quad \text{for} \quad \tau > 0 \tag{5}$$

then

$$C(\epsilon,\tau) = C_c - \sum_{n=0}^{\infty} \left\{ \frac{4(-1)^n C_c}{\pi(2n+1)} - F_n \right\} \exp\left[-\tfrac{1}{4}(2n+1)^2\pi^2\tau \right] \cos\left[\tfrac{1}{2}(2n+1)\pi\epsilon\right] \tag{6}$$

where

$$F_n = 2\int_0^1 C(\epsilon',0)\cos\left[\tfrac{1}{2}(2n+1)\pi\epsilon'\right]d\epsilon' \quad (n=1,2,..) \tag{7}$$

We denote the set of Fourier coefficients F_1, F_2, .. by $\{F_n\}$.

Consider a package subjected to the cyclic environmental stress shown in Table I. Each cycle consists of two stresses, one at condition A, followed by another at condition B. At the beginning of the A-stress in the first cycle, the concentration profile may be described, via Eq. (7), by the set of Fourier coefficients $\{F_n(A,1)\}$. Equation (6) may then be used to calculate the concentration profile after the stress at condition A. This concentration profile may be Fourier decomposed into the set of Fourier coefficients $\{F_n(B,1)\}$, which is the set of Fourier coefficients at the beginning of the B-stress of the first cycle. The Fourier coefficients $\{F_n(B,1)\}$ may be used as the initial concentration profile for the next stress at condition B, and Eq. (6) can be used to calculate the concentration profile at the end of the first cycle. The concentration profile at the end of the first cycle is the set of Fourier coefficients, $\{F_n(A,2)\}$, which describe the initial profile at the beginning of the A-stress of the second cycle. This procedure may be iterated to find the set of Fourier coefficients which describe the concentration profile at the beginning of any stress.

Table I. Summary of environmental conditions for each part of a two-part cyclic THB stress with period p and duty cycle r.

	Stress Condition A	Stress Condition B
Ambient Temperature	$T_{A,a}$	$T_{B,a}$
Package Case Temperature	$T_{A,c}$	$T_{B,c}$
Die Temperature	$T_{A,j}$	$T_{B,j}$
Molding Compound Temperature	$T_{A,mc} = \frac{1}{2}(T_{A,j} + T_{A,c})$	$T_{B,mc} = \frac{1}{2}(T_{B,j} + T_{B,c})$
Ambient Relative Humidity	$H_{A,a}$	$H_{B,a}$
Relative Humidity at Die Surface	$H_{A,j}$	$H_{B,j}$
Duration	$t_A = r\,p$	$t_B = (1 - r)\,p$
Bias	V_A	V_B

Schematically, the evolution of the Fourier coefficients describing the initial profile for each stress period may be written

Cycle

1: $\{F_n(A,1)\} \rightarrow$ A stress $\rightarrow \{F_n(B,1)\} \rightarrow$ B stress $\rightarrow \{F_n(A,2)\}$

2: $\{F_n(A,2)\} \rightarrow$ A stress $\rightarrow \{F_n(B,2)\} \rightarrow$ B stress $\rightarrow \{F_n(A,3)\}$

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m: $\{F_n(A,m)\} \rightarrow$ A stress $\rightarrow \{F_n(B,m)\} \rightarrow$ B stress $\rightarrow \{F_n(A,m+1)\}$

Mathematically, this procedure leads to recursion relations which relate the Fourier coefficients of the concentration profile at the end of a stress, to those at the end of the immediately preceding stress. Since there are two stress conditions, there are two recursion relations:

$$f_n(B,m) = C_{A,c}\,[1 - E_{A,n}] + E_{A,n}\, f_n(A,m) \tag{8}$$

$$f_n(A,m+1) = C_{B,c}\,[1 - E_{B,n}] + E_{B,n}\, f_n(B,m) \tag{9}$$

where

$$F_n = \frac{4(-1)^n}{\pi(2n+1)}\, f_n \tag{10}$$

$$E_{A,n} = \exp[\,-\tfrac{1}{4}(2n+1)^2\pi^2\tau_A] \tag{11a}$$

$$E_{B,n} = \exp[\,-\tfrac{1}{4}(2n+1)^2\pi^2\tau_B] \tag{11b}$$

where

$$\tau_A = \frac{D(T_{A,mc})\,t_A}{l^2} \tag{12a}$$

$$\tau_B = \frac{D(T_{B,mc})\,t_B}{l^2} \tag{12b}$$

and where the moisture concentrations at the surface of the package may be calculated by

$$C_{A,c} = H_{A,a}\,P_{sat}(T_{A,a})\,S(T_{A,mc}) \tag{13a}$$

$$C_{B,c} = H_{B,a}\,P_{sat}(T_{B,a})\,S(T_{B,mc}). \tag{13b}$$

The recursion relations in Eqs. (8) and (9) may be used to calculate the Fourier coefficients of the moisture concentration profile at the beginning of any stress from the Fourier coefficients of the initial moisture concentration profile. In practice, however, after a few cycles all "memory" of the original concentration profile will be lost, and the profile will evolve between two functional forms. As m becomes large, we define the asymptotic Fourier coefficients of the concentration profiles at the beginning of the A-stress, and B-stress parts of the cycle as, respectively:

$$F_n(A) = F_n(A,m) = F_n(A,m+1) \quad (\text{m large}) \tag{14}$$

$$F_n(B) = F_n(B,m) \quad (\text{m large}). \tag{15}$$

Substitution of Eqs. (14) and (15) into Eqs. (8) and (9) gives a pair of simultaneous equations which may be solved for $F_n(A)$, and $F_n(B)$. These solutions for $F_n(A)$ and $F_n(B)$ may be substituted into Eq. (6) to give the asymptotic concentration profiles during the A-stress and the B-stress parts of the cycle. After some manipulation we find the following expressions:

At any time t $(0<t<t_A)$ during the A-stress the concentration profile $C_A(x,t)$ is given by

$$\frac{C_A(x,t) - C_{A,c}}{C_{B,c} - C_{A,c}} = \sum_{n=0}^{\infty} \left\{ \frac{4(-1)^n(1 - E_{B,n})}{\pi(2n+1)(1 - E_{A,n}E_{B,n})} \exp[\,-\tfrac{1}{4}(2n+1)^2\pi^2\tau_A \tfrac{t}{t_A}]\cos[\tfrac{1}{2}(2n+1)\pi\epsilon] \right\} \tag{16a}$$

Similarly, at any time t $(0<t<t_B)$ during the B-stress the concentration profile $C_B(x,t)$ is given by

$$\frac{C_B(x,t) - C_{B,c}}{C_{A,c} - C_{B,c}} = \sum_{n=0}^{\infty} \left\{ \frac{4(-1)^n(1 - E_{A,n})}{\pi(2n+1)(1 - E_{A,n}E_{B,n})} \exp[\,-\tfrac{1}{4}(2n+1)^2\pi^2\tau_B \tfrac{t}{t_B}]\cos[\tfrac{1}{2}(2n+1)\pi\epsilon] \right\} \tag{16b}$$

Our interest is the environmental condition at the die, particularly the relative humidity. Since the moisture concentration in the molding compound adjacent to the die is known via Eqs. (16), by setting x=0, we can use Henry's law to calculate the RH at the die as follows:

$$H_{A,j}(t) = \frac{C_A(0,t)}{P_{sat}(T_{A,j})S(T_{A,mc})} \quad \text{(A-stress)} \tag{17a}$$

$$H_{B,j}(t) = \frac{C_B(0,t)}{P_{sat}(T_{B,j})S(T_{B,mc})} \quad \text{(B-stress)} \tag{17b}$$

Calculation of Cycle-Averaged Acceleration Factor

Since we are dealing with a time-varying environmental stress, we shall need to consider a time varying acceleration factor. If a certain proportion of a population stressed at a standard environmental stress fails in a time interval du, and the same proportion fails in a time interval dt at an accelerated stress condition, then the time-varying acceleration factor is given by

$$\frac{du}{dt} = A(t) \tag{18}$$

or

$$u(t) = \int_0^t A(t')dt' \tag{19}$$

Eq. (19) may be interpreted as follows: u(t) is the duration of a standard stress which produces the same effect as a duration t of an accelerated stress. Generally, A(t)>1 for the way in which we have defined it[7].

For n cycles of a periodic environmental stress with period p, Eq. (19) may be written as

$$u(np) = np\ A_{ave} \tag{20}$$

where the cycle-averaged acceleration factor is defined as

$$A_{ave} = \frac{1}{p}\int_0^p A(t')dt' \tag{21}$$

Since u(np)/np can be interpreted as the ratio of time in standard stress to time in accelerated stress required to reach a given proportion of failures, then via Eq. (20), A_{ave} is interpreted as the effective acceleration for the cyclic environmental stress. A_{ave} is the main objective of our calculations.

For a two-part cycle such as described in Table I, Eq. (21) may be written

$$A_{ave} = r\ A_{A,ave} + (1-r)A_{B,ave} \tag{22}$$

where the average acceleration over the A-condition part of the cycle is

$$A_{A,ave} = \frac{1}{t_A}\int_0^{t_A} A(t')dt' \tag{23}$$

and similarly for $A_{B,ave}$.

For simplicity, THB acceleration models are often written as a product of separate temperature, humidity, and bias acceleration factors:

$$A(T,H,V) = A_T(T)\ A_H(H)\ A_V(V) \tag{24}$$

For a cyclic environmental stress each of T, H, and V are functions of time, but for any realistic two-part "rectangular-wave" environmental stress such as summarized in Table I, both T and V at the die reach the environmentally imposed values almost instantaneously. On the other hand, H at the die takes much longer to change because of the relatively slow moisture diffusion through the molding compound. With this in mind, we can substitute Eq. (24) into Eq. (23) so that Eq. (22) may be written

$$A_{ave} = r\ A_T(T_{A,j})\ A_V(V_A)\ \frac{1}{t_A}\int_0^{t_A} A_H[H_{A,j}(t')]dt' +$$

$$(1-r)\ A_T(T_{B,j})\ A_V(V_B)\ \frac{1}{t_B}\int_0^{t_B} A_H[H_{B,j}(t')]dt' \tag{25}$$

There are three limiting cases in which the evaluation of Eq. (25) is easy because the RH at the die is constant in each part of the cycle:

1. For environmental stress with the same temperature and relative humidity in both parts of the cycle, but with cycled bias in which no power is dissipated:

   $$H_{A,j}(t) = H_{A,a} = \text{constant}$$

   for any period and duty cycle (and similarly for $H_{B,j}(t)$). The humidity acceleration integrals in Eq. (25) may be replaced by $A_H(H_{A,a})$ and $A_H(H_{B,a})$, making A_{ave} a linear function of duty cycle, and independent of the period.

2. For environmental stress with any temperature, humidity, and bias in both parts of the cycle, but with stress duty cycles long in comparison to the moisture saturation time constant of the package, $\tau_A >> 1$ and $\tau_B >> 1$, the molding compound is "transparent" to moisture. The humidity at the die in this case is

   $$H_{A,j}(t) = H_{A,a}\frac{P_{sat}(T_{A,a})}{P_{sat}(T_{A,j})} = \text{constant}$$

   (and similarly for $H_{B,j}(t)$). The humidity acceleration integrals in Eq. (25) may be replaced by $A_H(H_{A,j}{=}\text{constant})$, and $A_H(H_{B,j}{=}\text{constant})$, making A_{ave} a linear function of duty cycle and independent of period.

3. For environmental stress with any temperature, humidity, and bias in both parts of the cycle, but with stress duty cycles short in comparison to the moisture saturation time constant of the package, $\tau_A << 1$ and $\tau_B << 1$, the molding compound equilibrates at a constant value, independent of x and t. This value may be computed by taking appropriate limits in Eqs. (16):

   $$C_A(x,t) = C_B(x,t) = \text{const} = \frac{\tau_A C_{A,c} + \tau_B C_{B,c}}{\tau_A + \tau_B}$$

   Substitution into Eqs. (17) gives the (constant) values of relative humidity in each part of the cycle. These constant values of RH make trivial the evaluation of the humidity acceleration integrals in Eq. (25). In this case A_{ave} is a complicated function of duty cycle, but is independent of the period.

If the period of the cyclic stress is comparable to the moisture diffusion relaxation times, then the integrals in Eq. (25) are non-trivial functions of period and duty cycle, and must be evaluated by the following procedure:

1. Evaluate moisture concentrations in the molding compound at the outer surface of the package in each part of the cycle by using Eqs. (13).

2. Use Eqs. (16) with $x = 0$ to calculate the time-dependent moisture concentration in the molding compound adjacent to the die in each part of the cycle.

3. Use Eqs. (17) to calculate the time-dependent relative humidity at the die for each part of the cycle.

4. Evaluate A_{ave} in Eq (25) by substitution of the time-dependent relative humidity function into a humidity acceleration model and integrate numerically the humidity acceleration function in Eq. (25). Gaussian integration is the most efficient way to evaluate the integral since the integrand is available analytically. In the applications in Sec. III, we used a 12-point Gaussian integration for each part of the cycle.

THB Acceleration Models

To evaluate the effective acceleration, A_{ave}, of a cyclic THB stress it is necessary to use a specific THB acceleration model. In this paper we shall use the following model:

$$A_T(T) = \text{Constant} \cdot \exp\left(-\frac{Q}{kT}\right) \qquad (26a)$$

$$A_H(H) = \text{Constant} \cdot H^b, \qquad (26b)$$

$$A_V(V) = 0 \text{ for } V=0,\ A_V(V)=1 \text{ for } V=5.5 \text{ volts}, \qquad (26c)$$

where the constants are chosen so that accelerations are unity for T = 85°C, H = 85%.

Peck[3] surveyed published THB data, and found that $Q = 0.79$ eV, and that $b = 2.66$ in the above model summarized the data reasonably well. However, almost all of this data related to failures by aluminum corrosion. In recent years, improvements in molding compounds have eliminated aluminum corrosion as a significant failure mechanism. Today, functional failures (such as bit failures in SRAMs) due to passivation defects are the dominant failure mechanism. This type of failure was first reported by Guan, et al.[8].

We have carried out a careful HAST study of the THB dependence of failure by the passivation defect mechanism using plastic-encapsulated SRAMs. Large numbers of units from several lots were split among several THB stress conditions. Functional testing of failed units showed that more than 99% of all failures were bit-type functional failures in the array. The SRAMs were functionally rastered to locate the defect, and the vast majority of defects were found to be very fine passivation "microcracks". These microcracks were very similar to those reported by Guan[8] et al., and were not due to gross mechanical damage of the passivation. Parallel studies on other test vehicles in which the individual transistors within a bit could be characterized has shown that the bit failures correspond to severe threshold voltage shifts on one or more of the transistors comprising the bit. These threshold shifts are caused by moisture reaching the transistor through the microcrack in the passivation. We found that the acceleration data is fitted by a model with the form of Eqs. (26), with $Q = 0.79$ eV, and $b = 4.64$.

III. Applications

In the following applications we shall use the model given by Eqs. (26), with $Q = 0.79$ eV, and $b = 4.64$. We assume a molding compound thickness over the die of 50 mils; typical of plastic DIPs, and we use the molding compound properties given by Kitano, et al.[2]. We also evaluate molding compound properties, such as D and S, at $T_{mc} = (T_j - T_c)/2$, where $T_c = T_j - (T_j - T_a)/3$.

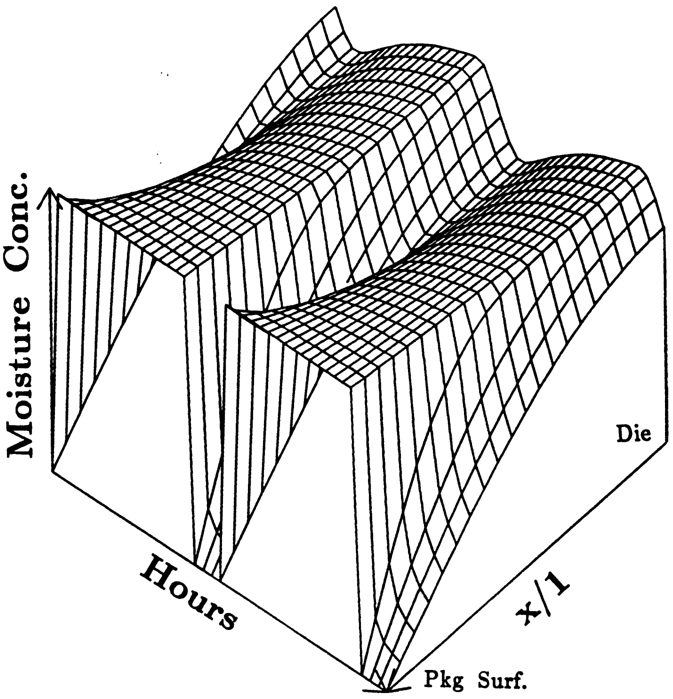
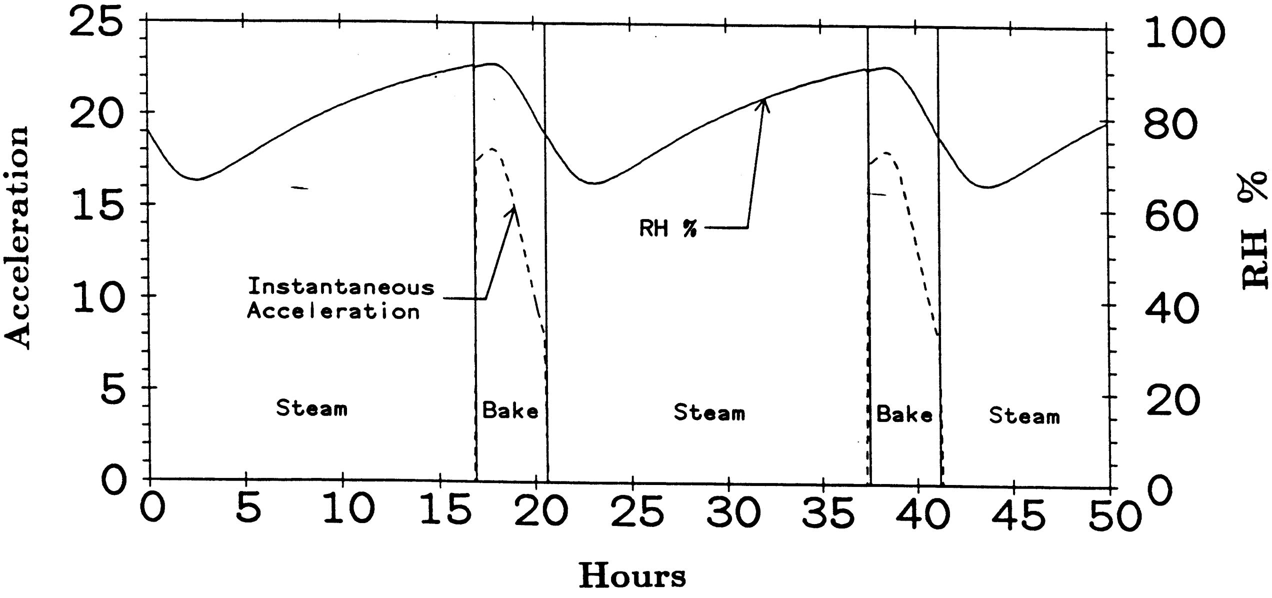


Fig. 1 Evolution of moisture concentration profile through molding compound over the die. Plotted for an environmental ambient cycling between 16.9 hours of steam (121/100/0) and 3.7 hours of biased bake (125/0/5.5). A "rectangular" time variation of moisture concentration at the surface becomes attenuated and phase-shifted at the die. Molding compound properties from Kitano, et al.[2] were used.

Fig. 2 Variation of the relative humidity at the die and instantaneous acceleration factor for the same stress cycle as shown in Fig. 1. During steam stress the instantaneous acceleration is zero because no bias is applied. The acceleration factor model in Eqs. (26), with Q = 0.79 eV, and b = 4.64 was used to evaluate the acceleration.



Cycled Steam/Bake ("Poor-Man's HAST")

For the model given in Eqs. (26), steady state application of either steam (T=121°C, H=100%, V=0V) or biased bake (T=125°C, H=0%, V=5.5 V, typical of burn-in) will not accelerate the failure mechanism. However, an environmental stress cycled between these two conditions provides a finite acceleration of the failure mechanism. In Fig. 1 we show the evolution of the moisture concentration profile in the molding compound for a particular cyclic stress consisting of 16.9 hours of steam (121/100/0) alternating with 3.7 hours of biased bake (125/0/5.5). The surface in Fig. 1 was calculated by using Eqs. (16).

The moisture concentration variation at the die (x/l=0 in Fig. 1.) may be used in Eqs. (17) to compute the RH variation at the die. The RH variation at the die is shown in Fig. 2 for the cyclic stress illustrated in Fig. 1. The RH and bias variations were substituted into Eqs. (26) to derive the instantaneous acceleration. The instantaneous acceleration is also plotted in Fig. 2. Note that the instantaneous acceleration is zero in steam because no bias is applied.

The instantaneous acceleration function displayed in Fig. 2 was numerically integrated for stress cycles with a range of periods and duty cycles, and the results are displayed as a function of period and duty cycle in Fig. 3. In Fig. 3 it is apparent that an optimum exists for a period of 20.6 hours and duty cycle of 81% of the cycle spent in steam (the same cycle displayed in Figs 1 and 2). The cycle-averaged acceleration at the optimal period and duty cycle is 2.7, relative to steady-state biased 85/85 with no power dissipation.

Effect of Power Cycling for 85/85 or 130/85 HAST Stress

A common situation in practice is steady state application of temperature and humidity, and cyclic application of bias. If there is no power dissipation when bias is applied, then the optimal stress must be application of bias 100% of the time. However, if power dissipation is appreciable then some advantage may be gained by cycling the bias on and off. We will explore effect of power dissipation, period and duty cycle on the cycle-averaged acceleration, assuming the model of Eqs. (26) with Q = 0.79 eV and b = 4.64.

In Fig. 4 is plotted the cycle-averaged acceleration as a function of period and duty cycle for 85/85 stress and for T_j-T_a=20°C. It is apparent that A_{ave} is only a weak function of the period. The maximum occurs for a period of 61.2 hours and a duty cycle of bias on 32% of the time. At the optimal period, A_{ave} is plotted as a function of duty cycle in Fig. 5 for various levels of power dissipation. For T_j-T_a=0 and T_j-T_a=5, the maximum value of A_{ave} occurs for a duty cycle of 100%. However, when T_j-T_a exceeds 8 degrees, the optimal duty cycle becomes less than 100%.

To evaluate the benefit of cyclic application of bias, we define a figure of merit for cycled bias as:

$$A_{ratio} = \frac{A_{ave}\ (\text{optimum})}{A_{ave}\ (\text{duty cycle} = 100\%)} . \qquad (27)$$

Fig. 3 Cycle-averaged acceleration factor, A_{ave}, as a function of period and duty cycle for an environmental stress cycling between steam (121/100/0) and biased bake (125/0/5.5). The acceleration factor model in Eqs. (26), with Q = 0.79 eV, and b = 4.64 was used to evaluate the acceleration.

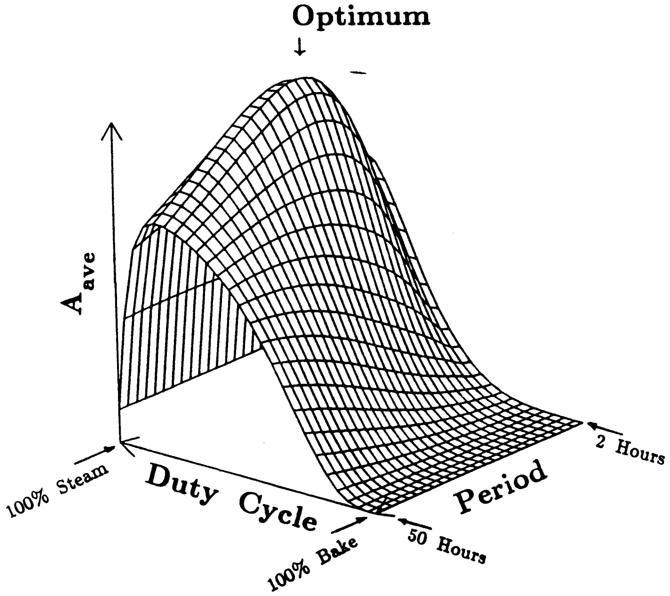


Fig. 4 Cycle-averaged acceleration factor, A_{ave}, as a function of period and duty cycle for an environmental stress cycling between unbiased 85/85 and biased 85/85. During the biased portion of the cycle, T_j-T_a = 20°C. The acceleration factor model in Eqs. (26), with Q = 0.79 eV, and b = 4.64 was used to evaluate the acceleration.

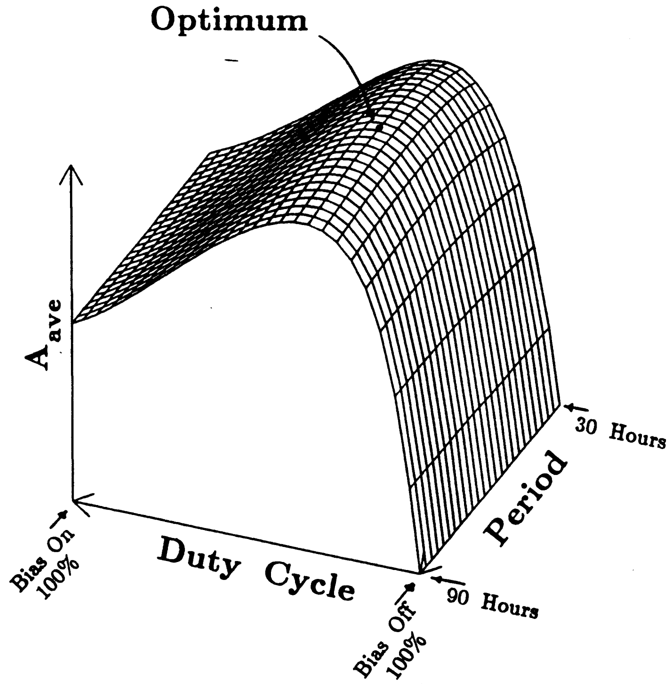


Fig. 5 Cycle-averaged acceleration factor, A_{ave}, for power-cycled 85/85 at optimal period (61.2 hours) as a function of duty cycle for various levels of power dissipation, T_j-T_a. The optimal duty cycle and optimal cycle-averaged acceleration is indicated by •.

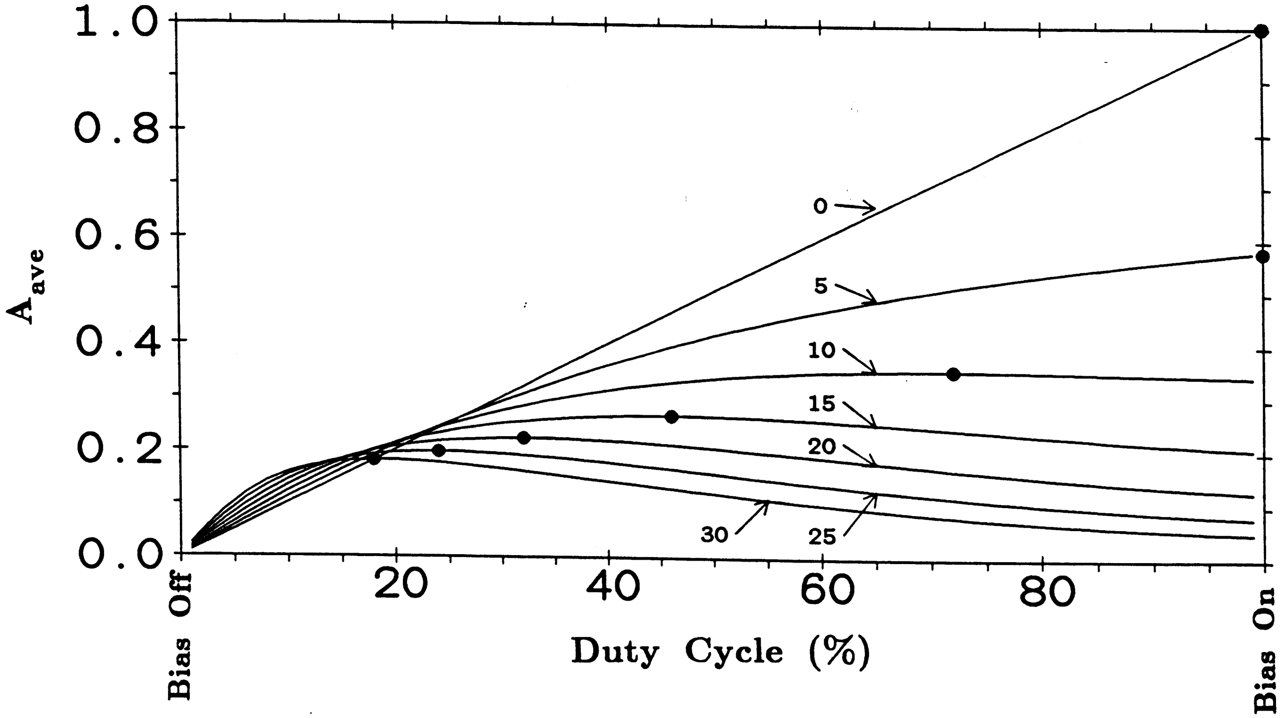


Fig. 6 Effect of power dissipation on optimal cycling conditions for power-cycled 85/85 stress at the optimal period (61.2 hours). For values of T_j-T_a less than 8°C, the optimal duty cycle is with bias on 100% of the time. A_{ratio}, Eq. (27), is a measure of the advantage to be gained by employing cyclic bias.

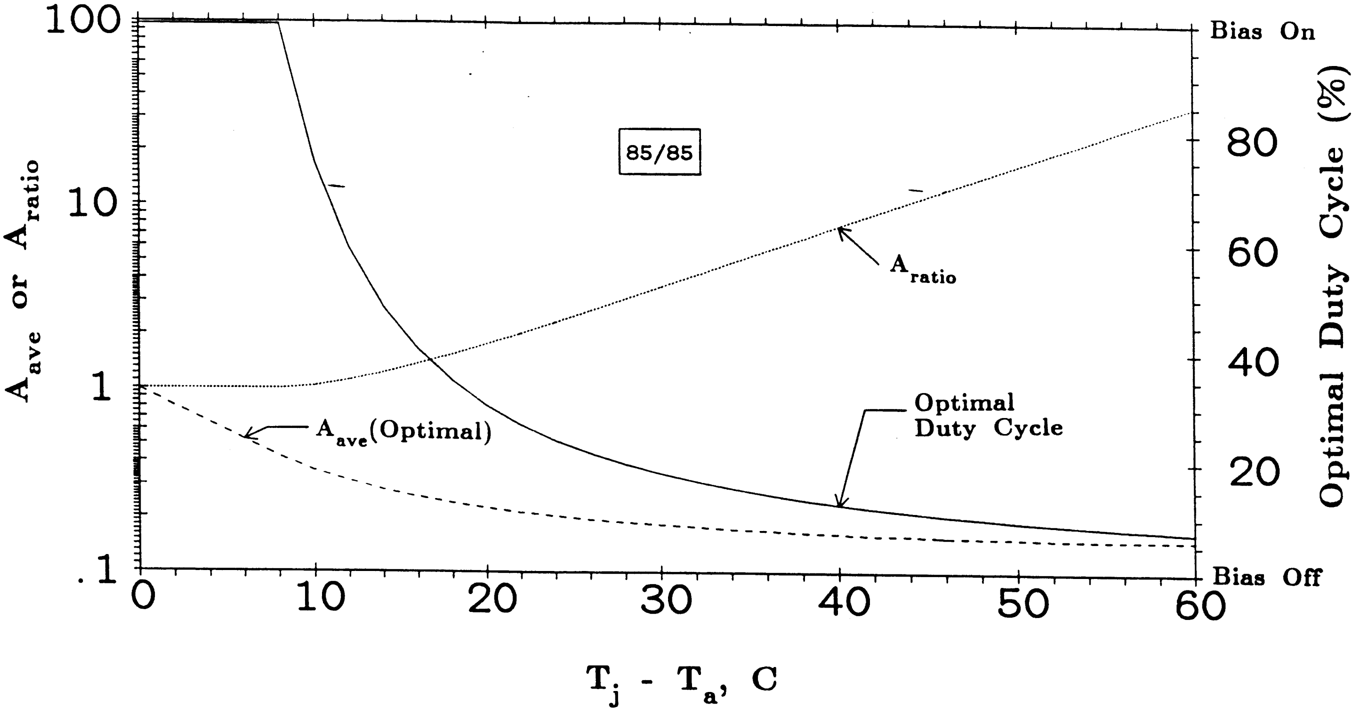
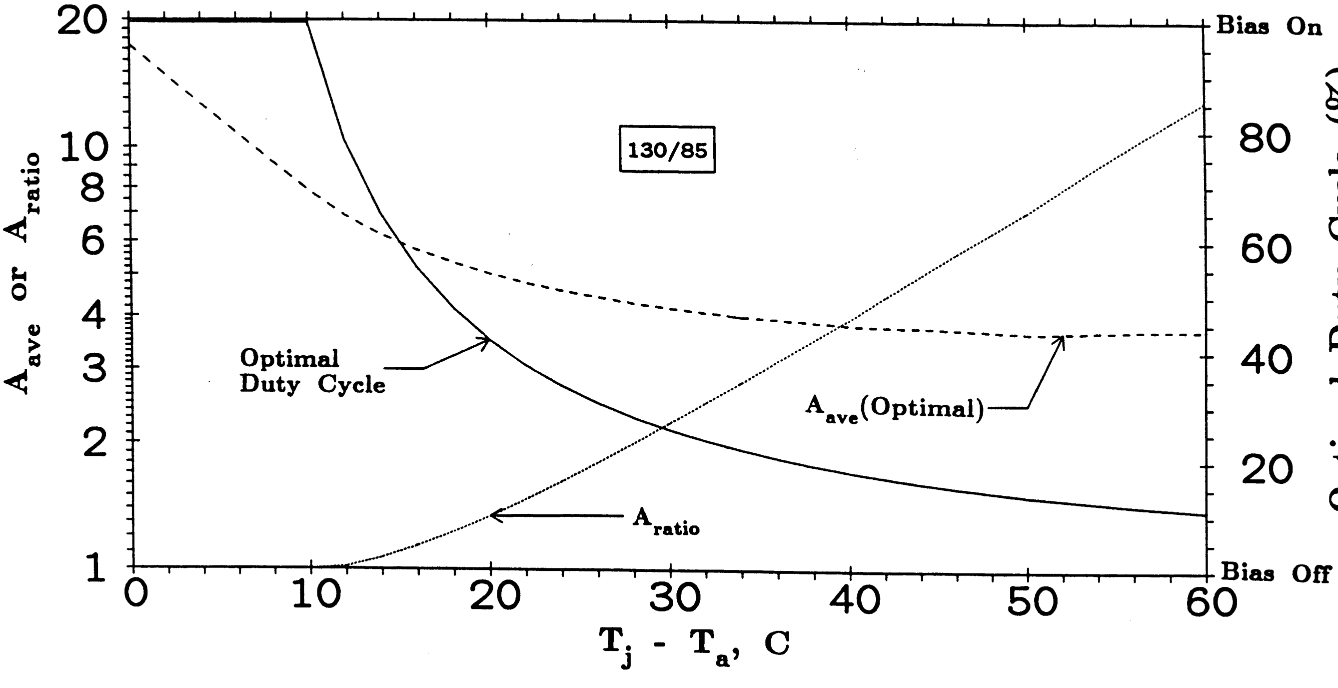


Fig. 7 Effect of power dissipation on optimal cycling conditions for power-cycled 130/85 (HAST) stress at the optimal period (10.8 hours). For values of T_j-T_a less than 10°C, the optimal duty cycle is with bias on 100% of the time. A_{ratio}, Eq. (27), is a measure of the advantage to be gained by employing cyclic bias.



This gives the acceleration advantage of using cycled bias instead of 100% on bias for a power-dissipating biased 85/85 stress. In Fig. 6 we plot the optimal duty cycle, the value of A_{ave} at the optimal duty cycle, and the value of A_{ratio}, as a function of power, T_j-T_a, all for the optimal period of 61.2 hours. For example, for T_j-T_a=20°C, the optimal duty cycle is a 32% on-time, the acceleration is 0.22 relative to a non-dissipating 85/85 biased stress, and the acceleration is 1.75 times quicker than if the power-dissipating stress condition were applied 100% of the time.

For 130/85 HAST, A_{ave} is also a weak function of cycling period, with an optimal period of 10.8 hours. For this optimal period, the optimal duty cycle, A_{ave}, and A_{ratio} are shown in Fig. 7.

Figures 6 and 7 can be used to decide whether to use cyclic bias to accelerate 85/85 or 130/85 THB stress, and give an idea of the magnitude of the benefit that will be achieved. It must be remembered that these figures are specific to the model of Eqs. (26), with Q=0.79 eV, and b=4.64. If the RH dependence is stronger than this model, then cyclic application of bias will have an advantage over DC application of bias at lower power dissipations than are shown in Figs. 6 and 7.

Conclusions

1. A key element of the model we have provided to evaluate the effect of cyclic THB stress is an analytical solution to the one-dimensional diffusion equation, Eqs. (16), which admits convenient calculation of the local moisture environment at the die.

2. The model requires knowledge of an acceleration factor model. One might determine the acceleration factor model for a particular test device which dissipates negligible power and then use the analysis presented here to determine optimal cyclic stress conditions for other power-dissipating products manufactured using the same process.

3. The applications studied were for an acceleration model determined for a passivation defect mechanism, which is a failure mechanism of current interest. For this mechanism, we find that Acceleration = Constant • exp(-Q/kT) • H^n, where Q = 0.79 eV, and n = 4.64.

4. We explored the interesting but not very practical case of a cyclic stress alternating between (unbiased) steam (121/100/0) and biased (dry) bake (125/0/5.5) with no power dissipation, assuming the passivation defect mechanism. We find that

   - The effective acceleration is a strong function of both duty cycle and bias, with a period of 20.6 hours, and an optimal duty cycle of 81% of the time spent in steam.

   - The RH at the die never reaches 100% during the stress.

   - The optimal acceleration is 2.7, relative to steady state application of biased 85/85. This acceleration is equivalent to a steady-state application of a THB stress of 100/85.

   - A significant disadvantage of the method is that units must be socketed 18 times to reach an equivalent of 1000 hours of 85/85.

5. For the more practical case of power-cycled 85/85 and 130/85 HAST, assuming the passivation defect mechanism, we find:

   - For values of T_j-T_a< 8°C for 85/85 or T_j-T_a < 10°C for 130/85 there is no advantage in power cycling.

   - When power dissipation is large enough that cycling the power can provide an advantage, the optimal acceleration is a weak function of the period, but is a strong function of duty cycle.

   - For T_j-T_a> 8°C for 85/85 or T_j-T_a> 10°C for 130/85, the optimal duty cycle decreases rapidly. We provide graphs (Figs. 6 and 7) which give the optimal duty cycle, and the advantage to be expected, as a function of power dissipation for 85/85 and 130/85 THB testing.

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$$S(T) = 2.76 \times 10^{-8} \exp\left(\frac{Q_s}{kT}\right) \quad \frac{\text{Moles}}{m^3\ \text{Pa}}$$

where T is in degrees K, k is Boltzman's constant ($k = 8.61 \times 10^{-5}$ eV/°K), and Q_s=0.40 eV. They also give the diffusion coefficient for moisture in molding compound as

$$D(T) = 4.7 \times 10^{-5} \exp\left(-\frac{Q_d}{kT}\right) \quad \frac{m^2}{\sec}$$

where $Q_d = 0.50$ eV.

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$$P_{sat}(T) = 1.2135 \times 10^{23} \exp\left[-4.0843 \ln(T) - \frac{6505.72}{T}\right] \quad \text{(Pa)}$$

where P_{sat} is in Pa, and T is in degrees K. The expression is accurate to better than 1.5% in the temperature range from 0°C to 200°C.

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$$f_2(t) = A(t)\ f_1[u(t)]$$

$$F_2(t) = F_1[u(t)]$$

$$h_2(t) = A(t)\ h_1[u(t)]$$

where

$$u(t) = \int_0^t A(t')dt'.$$

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