Use of Life Tested Parts

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History

The use of life tested parts in flight hardware continually becomes an issue for customers. The life test referred to here is the standard life test called for during Quality Conformance Inspection (QCI). This is typically a dynamic burn-in lasting for 1000 hours with an ambient temperature of +125°C. The concern arrives because customers believe a significant portion of the part's useful life has been consumed by this accelerated testing. This document shows that life tested parts are usable as normal valued product.

Product Assumptions

This report addresses high reliability product from an Intersil qualified wafer fabrication process built in hermetic packages. It does not address commercial nor industrial product. It does not address any non-hermetic packaging techniques. It is assumed that the part meets all design rules for the process and is fully qualified.

Product Aging

The life cycle of an electric product follows the well known bathtub curve as shown in Figure 1. It should be noted that the time axis is a logarithmic axis. Each unit is a factor of 10 greater than the previous unit distance. Time counts as 1, 10, 100, 1000 hours. The early life failure rate is dominated by the infant mortality failures. This is a decreasing failure rate. Infant mortality failures are generated by manufacturing defects that are random in nature. Examples of these are particles in the interlevel oxides creating shorts between metal layers. Scratches and thin-oxide pinholes are also examples of these types of failures. These failures follow a log-normal failure distribution with a short mean life time and a high sigma. They also represent a small fraction of the total population. High reliability product receives a burn-in to remove this defective portion of the population. The maximum allowed amount can range up to 5% without causing corrective action to take place during manufacturing. The Percent Defective Allowable (PDA) defines the limit on burn-in loss before corrective action takes place.

The middle region is the constant failure rate portion of the life curve. Here the failures are randomly distributed in time. The burn-in has removed the infant mortality portion of the product. The probability of failure is governed by the exponential distribution. The desire is to get this failure rate as low as possible because this is the useful life of the product. The customer would receive the product at the beginning of this portion and install it into hardware for the end user. Life testing is used to estimate the failure rate in this portion of the curve. In reality, the failure rate observed by our customers is lower than the predicted failure rate based on life testing. One reason for this is because the sample sizes used in life test are too small to resolve the true failure rates. As an example, to verify 10 FITs (1 FIT = 1 failure in 10^9 hours) at 60% Upper Confidence Limits (UCL), with two failures which would require a sample size of 46,300 units. For smaller failure rates, the sample sizes increase greatly.

The final region of the curve is the wearout region. As can be seen, this region is characterized by an increasing failure rate. At this point the parts have reached the end of their life and begin to fail rapidly. Wearout is also modeled by a log-normal distribution with a very large mean failure time but with a very tight sigma. When wearout starts to occur the population of parts begin to fail closely spaced in time. Many people have experienced this with light bulbs in their house.

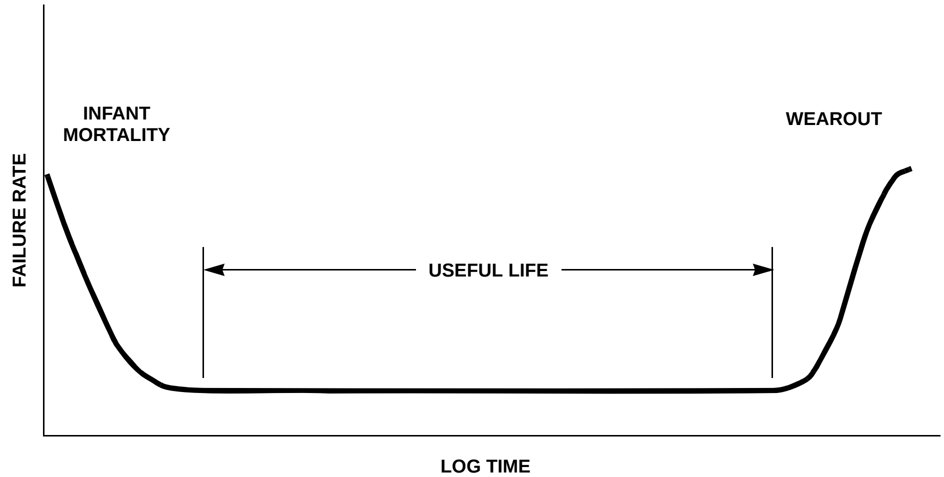

FIGURE 1. BATH TUB CURVE OF A PRODUCTS LIFE CYCLE

When one bulb burns out, within a few days, they all burn out. Examples of mechanisms responsible for wearout in integrated circuits are electromigration, Time Dependent Dielectric Breakdown (TDDB), stress void generation, and hot carrier degradation. Each of these mechanisms can result in circuit failure.

Customer Concerns

The issue customers have with using life tested parts is how much of the useful life is consumed by the accelerated life test? Where are the parts in the life cycle after the life test? As described earlier, the desired region for device operation is in the constant failure rate region or middle region of Figure 1. A part should be aged by burn-in long enough to remove the infant mortality but not near wearout. The burn-in should put the parts at the beginning of the constant failure rate curve. If the burn-in is not long enough some of the infant mortality may be present during the useful life. This situation manifests itself in a higher constant failure rate during the useful life. The addition of a life test ensures that the infant mortality portion of the population is removed and a lower constant failure rate is achieved. The next section will show that even after a life test, the onset of wearout is still very far out in time.

Wearout Onset

The onset of wearout is determined by evaluating individual failure mechanisms on specific test structures. Because these parts are high reliability products, highly accelerated testing techniques must be used to gather data in a reasonable time. An example of this technique is for electromigration. Figure 2 shows an NIST electromigration test structure. This is a four-terminal device for measuring resistance of the test strip. Current is forced through the structure at elevated temperatures. Temperatures in the +200°C to +250°C range are not uncommon. Current densities in excess of 10^6 amps/cm^2 are also not uncommon. These temperatures and currents are much greater than observed or allowed in an actual circuit. These highly accelerated conditions allow failure distribution to be generated in a relatively quick time frame.

The data gathered from these tests is used to define the ground rules for allowed design or operation of the parts. As in the electromigration example, the data gathered defines the metal line widths used to layout the circuit. The circuit designer determines the current a metal line must handle using circuit simulation techniques. From this, the size of the metal line is defined by the layout ground rules. Intersil uses a wearout criteria of no more than 1% failure in 10 years of constant operation at worst-case conditions for that wearout mechanism. The junction temperature for most mechanism is considered to be +175°C. In some cases the criteria is even tighter (electromigration is 0.1%). This may not sound like a high reliability limit but the stresses used for wearout testing are constant bias with a circuit configuration designed to cause the most rapid aging possible. A good example of this condition is for hot carrier stressing. Hot carriers are produced at the drain side of a MOSFET transistor when the transistor is saturated. The high fields at the drain can provide some carriers enough energy to be injected into the gate oxide altering the threshold of the transistor. This action degrades the performance of the transistor and can result in circuit failure. The stress condition to accelerate hot carrier degradation is at peak substrate current. This is typically where the gate is biased to about half the voltage of the drain. This condition causes the maximum charge injection into the oxide. In normal transistor operation, a transistor would only see this condition a small fraction of the time.

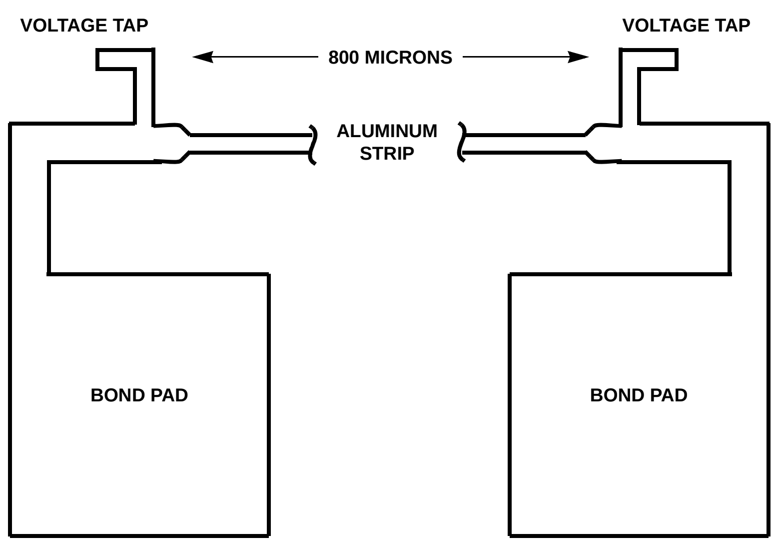

FIGURE 2. METAL ELECTROMIGRATION TEST STRUCTURE

This condition occurs only when it is switching states between an off and on condition. CMOS logic would see small pulses of this current each time the logic gate switched states. Hot carrier injection does not occur unless the gate switches states and then only for a fraction of the time it takes to switch.

In addition to the stresses being more severe than what is found in a circuit and end user is unlikely to operate the devices at the worst case conditions. In real life, the wearout conditions will be longer than 10 years. To illustrate, consider electromigration related failures. Electromigration has two parameters that determine life time: temperature and current density. For this example, a customer operates the part at a junction temperature of +80°C rather than +175°C. The reliability has moved from 0.99 at 10 years to 0.99 at 1310 years. The reliability at 10 years is now virtually 1.00 (no failures).

Life Test Aging

Life testing is typically performed at +125°C for a 1000 hours of duration. As an alternate it could be run for 800 hours at +135°C. This time is equal to about 1 year at +80°C. Given the electromigration example above we still have 1309 years left before wearout provided we have the maximum current density in all metal lines. Maximum current density is typically not the case during life testing. The burn-in chambers are not capable of running the part at their rated speed, so the actual stress time is less than 1 year for this failure mechanism.

Hypothetical Part

This section develops an actual example and the mathematics necessary to evaluate the failure rate. The bathtub curve shown in Figure 1 is composed of three probability distributions. The first and last are lognormal and the middle is an exponential. A lognormal distribution has a probability density function as shown in Equation 1. The two key values are μ and σ. These parameters determine the location in time and the shape of the distribution. The Exponential distribution has a probability density function as shown in Equation 2. The exponential distribution has only one key parameter which is λ. The exponential distribution is unique in that it has a constant failure rate which is defined by λ. The failure rate of a lognormal distribution is defined by Equation 3 where F(t) is the cumulative density function. This is formed by integrating the probability density function from 0 to t.

$$f(t) = \frac{1}{\sigma t \sqrt{2\pi}} e^{\frac{-1}{2}\left(\frac{\ln(t) - \ln(\mu)}{\sigma}\right)^2} \qquad \text{(EQ. 1)}$$

$$f(t) = \lambda e^{-\lambda t} \qquad \text{(EQ. 2)}$$

$$\lambda(t) = \frac{f(t)}{1 - F(t)} \qquad \text{(EQ. 3)}$$

The infant mortality portion of the curve is characterized by a short life time and a large variability. Normal processing for these high reliability products includes a burn-in of at least 168 hours. A sample of these parts is placed on a life test for 1000 to 3000 hours. In a typical case the burn-in loss is less than 3% and the life test loss is close to zero. With the time set to 168 hours and $\sigma = 4$ one can calculate the value of μ so 90% of the defective parts would fail by 168 hours when operated at a temperature of +125°C. This value comes out to be $\mu = 1$. The wearout portion is calculated in a similar fashion. The criteria Intersil uses for wearout is less than 1% failure in 10 years at +175°C. The wearout portion will fail very tightly grouped. Ten years is 87,660 hours. Using the values of 2.85E+5 and 0.5 for μ and σ show that ~1% of the parts will fail in 87,660 hours at +175°C. The last distribution is the center portion. This is the useful life of the parts. The inverse of the failure rate for this portion is the Mean Time Between Failures (MTBF). If 10 FITs is assumed (10 failures in 10^9 hours) then the MTBF would be 11,407 years.

These three sections are all at a different temperatures. The infant mortality portion is calculated using +125°C, the maximum temperature in useful life is typically +80°C, and the wearout is calculated at +175°C. To equate the three regions to the same temperature requires an activation energy and the Arrhenius equation. The Arrhenius equation relates the rates of reaction of chemical processes. This equation can be used to relate the rate of failure for one mechanism at two different temperatures. Equation 4 shows the Arrhenius equation. R_0 is a constant based on the chemical reaction and E_A is the activation energy for the process. Higher activation energies indicate that a reaction is greatly accelerated by temperature. The value T is the absolute temperature and k is Boltzman's constant, 8.62E-5 eV/K. When used in the form of an acceleration factor, the Arrhenius equation has the form shown in Equation 5 where T_{Use} and T_{Stress} are the temperature a USE and STRESS conditions, respectively.

$$R = R_0 e^{\frac{-E_A}{kT}} \qquad \text{(EQ. 4)}$$

$$A_f = e^{\frac{E_A}{k}\left(\frac{1}{T_{USE}} - \frac{1}{T_{STRESS}}\right)} \qquad \text{(EQ. 5)}$$

The three regions can be normalized to provide the failure distribution of this fictitious part at 80°C. The resulting failure rate curve is shown in Figure 3. Curve A is with no burn-in. Curve B is with a 75 hour, +125°C burn-in. Curve C is with a 1000 hour life test at +125°C. The failure rate drops significantly with a burn-in and the life test only improves the failure rate. As can be seen the wearout portion is not affected by the life test. The life test only serves to further remove the infant mortality portion of the failure population.

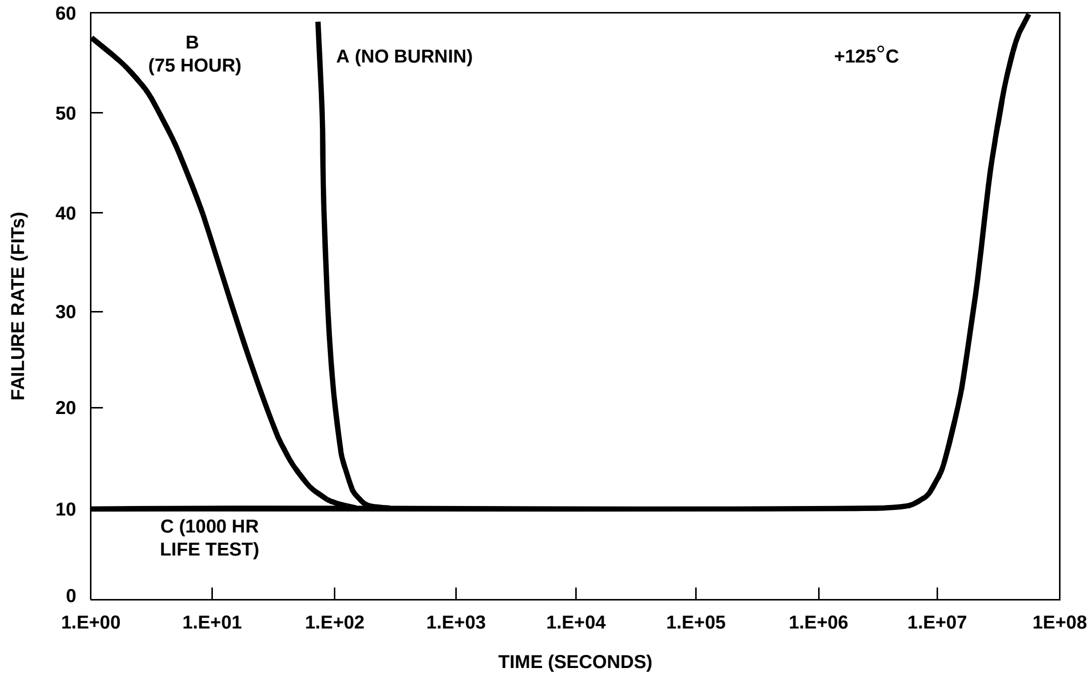

FIGURE 3. FAILURE RATE CURVES FOR 0 HOURS, 75 HOURS, AND 1000 HOURS OF BURN-IN

Conclusions

The onset of wearout for high reliability product is very far out in time. Life testing provides an extra burn-in to age the parts and remove any residual infant mortality failures. This has the effect of lowering the failure rate during the useful life. The intrinsic (defect free) population is not harmed by the extra burn-in time of life test.