GaAs IC Reliability Qualification by Levels

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Introduction:

GaAs circuits are emerging into commercial and consumer markets at an increasing rate. The expansion of wireless and fiber optic telecommunications applications will drive integrated circuit costs down. To respond to the lower price expectations, manufacturers will need less expensive qualification solutions. In spite of this overall trend towards economy, some customers expect more rigorous qualification testing. To meet the needs of all customers, various levels of qualification are needed. This discussion describes multiple scenarios of reliability qualification options.

Purpose:

The intent of this work is to describe a qualification methodology with emphasis on various natural plateaus which are dictated by the intended use of the device. Special emphasis will be placed upon aspects of qualification as they pertain to failure mechanisms, failure distributions, activation energies, test methods, and field failure causes.

The State of Reliability:

Best commercial practice often results in compromise. Customers are expecting better and better reliability. Currently, these expectations are for devices that have failure rates between 100 and 10 FIT. A FIT is a failure rate term amounting to 1 failure per billion device hours. A billion hours is equivalent to 114,000 years, so 100 FIT is approximately equal to a failure rate of one device per millennia! Proving failure rates at levels below 100 FIT is an expensive proposition. Under the assumption of constant failure rates (Chi Square calculation) with 90% confidence; and assuming that a 1,000 hour lifetest is conducted at 200°C; a test with zero failures would require a sample size of 1,266 devices, if an activation energy of 1.0eV is used as an acceleration factor. Sample size requirements for a good prediction of failure rates is just one of the costs of qualification. If fixturing, engineering, electrical test, and package testing is considered a "typical" commercial qualification has been recently quoted at around $25,000. As device prices continue to plummet, the expense of qualification becomes more difficult to justify. The market forces of increasing expectations for reliability and expectations of decreasing part prices present a challenge to the reliability engineer to perform economic qualifications that are still meaningful.

One problem with generating meaningful numbers is the large number of variables that can impact reliability numbers. In fact, reliability "experts" cannot even agree about which parameters are appropriate to measure reliability. For example, failure rates, median lives, and number of defects are each used for reliability measurements. For failure rates alone, the variables of device hours, number of failures, mission time, time to failure, acceleration temperature, operating temperature, activation energy, confidence levels, and temperature measurement methods can each be manipulated independently to generate favorable reliability numbers. The key to understanding these statistical influences is to find a method of comparing the various data using a technique that normalizes the variables. Graphical methods are often useful, and this author suggests an "activation energy graph" as one good choice. The activation energy graph merely plots median lifetimes versus temperature.

Description of Levels:

Understanding reliability requires a thorough knowledge of: Failure Mechanisms, Failure Distributions, Acceleration Factors, Failure Criteria, and Application Factors. Typically this knowledge is gained through testing, but analysis of field failures is another important gauge of applicability. One additional part of reliability involves screening, particularly for applications with stringent requirements. Very few

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programs can afford to acquire complete knowledge of all these aspects from scratch, so compromises are often made, albeit with good engineering judgment. Compromises of knowledge can be ranked into various levels. Definitions of levels and their rankings will depend on individual experience and biases of the person performing the evaluation. The following levels and their assessments are provided as examples:

1. Similarity:

Similarity is lowest form of reliability qualification. Processes, products, and packages may be qualified by being similar to something which has been previously qualified to a higher level. This level is usually accomplished with an engineering argument based upon logic. For example, if a certain package style is capable of completing a series of environmental tests, then it is likely to pass similar tests, regardless of the design of the die. Therefore, many different ICs in the same type of package could be "qualified by similarity." This level is accomplished with the lowest amount of resources, but also carries the highest risk of omission, since tests are not actually conducted for each qualification.

2. Comparison:

Comparison is the next level of qualification. Comparison involves specific testing which compares results, but does not necessarily meet goals of reliability for definable time periods. These tests generally collect attributes, not variables. For example, many package-related qualifications involve "standard" testing which does not have accepted acceleration factors to compare with normal life or expected use conditions, such as lead fatigue or temperature cycling. This is not to say that such testing doesn't have value, but favorable results usually can't be easily translated to specific statements about expected lifetimes. For example, what lifetime corresponds to 100 temperature cycles? We all know that it is good for a device to pass 100 temperature cycles without failure, but there is not necessarily an acceleration factor that can be used to translate the result to a failure rate or median life. Another form of comparison testing involves information on thermal performance, absolute maximum ratings, or other parameters that generally measure quality attributes which don't have direct correlation to reliability. In fact, results of comparison testing are often measured by attributes, not variables. In it's most literal form, qualification by comparison is achieved by matching results of previously performed tests or baselines.

3. Goal Certification:

The Goal Certification Level of qualification involves meeting specific goals involving life. For example, lifetests confirming reliability performance for warranty periods or expected use periods may confirm goals. This level is discerned from Comparison Level since the results can be directly translated to longevity. This level is different from the next higher level since actual end-of-life need not be measured. For example, a one year long lifetest may be conducted without acceleration to cover an expected warranty period of 1 year. Knowledge of degradation modes, failure mechanisms, lifetimes, or acceleration factors will not likely be discovered. However, the data could be convincing in terms of knowing that products can survive reliably during the warranty period. Various goals could be certified using this level of qualification and pre-determined acceleration factors. This is the most common form of qualification, particularly defined in military specifications.

4. Measurement:

The Measurement Level of qualification involves deliberate measurement of end-of-life. This means testing to failure. Multiple end-of-life tests at various conditions result in determination of acceleration factors. The Measurement Level of qualification is the only level that will always determine failure mechanisms, failure distributions, and acceleration factors. This level of qualification is the most desired and often the most costly.

Choices:

With the previous list of four levels of qualification, choices are available to meet various requirements. By using economics and program requirements, the appropriate levels can be assigned. For example, many programs cannot afford to test every device using the measurement level. Recognizing this limitation, the measurement level might be reserved for evaluation of variables that impact the most products, such as process evaluation structures. In this manner, the most reliability information would be gained on the base process which affects all devices constructed using it. In this scenario, the next most global characteristic might be design. Therefore, design variable could be tested using the goal certification level. In this manner, all products using the same design characteristics would be known to have met certain goals for reliability. Finally, each individual product could be comparison tested to double check the more costly evaluations. Each individual product's reliability might not be exactly determined, but at least the testing should be more affordable. The similarity level could also be evoked to claim qualification of the package style as previously described in the description of similarity.

There are other methods besides economics for determining appropriate qualification testing levels. One of the best indicators for guiding qualification level selection, is field failures. What better method is there for selecting which areas get the most costly testing than those where the failures are actually occurring?

Acknowledging the various qualification levels and the choices that they offer brings a problem: a decision about the appropriate level must be consciously made. Ignoring qualification levels and performing the "standard" test is undeniably the safe way out for programs that cannot afford any mistakes. The best testing may not be selected, but if something went wrong, then blame cannot be assigned to someone who performed "the standard."

Recommendations:

IC suppliers need to work to clearly define various qualification levels that make sense for their processes. Tradeoffs for each level need to be defined to help customers make decisions about qualifications. The suppliers should try to focus on failure mechanisms that actually occur on devices in use, and not just the mechanisms that are generated in accelerated reliability tests.

Customers need to educate themselves on reliability. Instead of demanding the highest MTBF or the lowest failure rate number, they should ask questions about how devices fail, why they fail, and what can be done to prevent failures. To assist suppliers, customers need to give feedback on actual failures they are experiencing and return devices with detailed descriptions of the failure modes encountered.

Both suppliers and customers need to work together to eliminate application errors, and to define qualification procedures. A recommended procedure would be to:

> Jointly set the reliability requirements in a format that both sides can understand.
> Discuss the various levels of qualification that are available.
> Assess the risks involved with each level of qualification.
> Determine the cost of the qualification and the resources available to accomplish the tasks.
> Engineer the appropriate qualification using information from each of the above steps.

Summary:

Reliability is evolving, and it will continue to evolve. As requirements get more stringent and prices get lower, new methods will have to be developed in order to assure adequate qualification of ICs. This work describes several aspects of GaAs device reliability which are often overlooked. Definition of best commercial practices and high reliability qualification techniques must occur for the end user to identify and specify cost effective methods for obtaining products which are fit for the intended use.