http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet

Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 8 (7): 1080-1083, 2009
ISSN 1812-5638

A Novel Approach for MMIC Reliability Testing Based on Weibull Distribution

Zheng-Liang Huang, Fa-Xin Yu, Shu-Ting Zhang, Yao Zheng and Ji-Xin Liu
Institute of Astronautical Electronics Engineering,
School of Aeronautics and Astronautics Zhejiang University, Hangzhou, 310027, China

Abstract: This study describes a reliability test method for reliability evaluation of MMICs (Monolithic Microwave Integrated Circuits) in product inspection applications. It takes advantages of the potentiality of various reliability test approaches, aiming at meeting the requirement of MMIC development. In this way, quicker realistic reliability assessment can be also realized for new products or those without historic data. Applications of this prediction model to real MMICs are illustrated and a general overview of the corresponding parameters' influence is given. The results of this study indicate in order to predict the GaAs MMICs reliability in a fixed shorter time and smaller sample size, one can design the test based on the combination of empirical methods and statistical methods. This study proposed a reliability prediction combing Arrhenius method and Weibull statistical method and we find Weibull slope is important for the MMICs reliability characterization. The analysis predicts excellent reliability for MMICs based on Arrhenius method, Weibulll method and zero fails result.

Key words: MMICs, reliability, accelerated testing, Weibull distribution

INTRODUCTION

GaAs MMIC reliability is the probability that a device will perform its intended function during a specified period of time under the specified operating environment. The reliability of MMICs has been extensively investigated (Pecht and Nash, 1994; Foucher *et al*., 2002; Gu and Pecht, 2007). Generally, the method used for reliability prediction is a matter of contention. It is understood that the benefits of a reliability prediction depend on the accuracy and completeness of the information used to conduct the prediction. Unfortunately, on the one hand, the long assessment time required is not often acceptable; on the other hand, the economic constraints allow this type of scheme to be used only by large companies. With the reliability of MMICs improved and the shorter production duration required, the ability to predict the reliability is very important but very limited nowadays. Thus, it must draft a test plan to understand the lifetime of MMICs and the tendency of reliability versus time.

Our proposed approach is usually used for items that are undergoing an enhancement. It starts with the collection of past experience data. If the product does not have a direct similar item, then lower level similar circuits can be exploited. This MMIC reliability test method mainly involves thermal stress (175-275°C channel temperature), shorter test time and smaller sample size. The Arrhenius law, Weibull and lognormal distributions will be applied in this study. In particular, a MMIC reliability evaluation approach is presented and a general overview of the corresponding parameters' influence are given.

FAILURE MECHANISM

GaAs MMIC failures can be classified as either catastrophic or degradation failures. Catastrophic failures render the device totally nonfunctional, while degradation failures result in an electrically operating device that shows parametric degradation and limited performance. Although, both passive and active components of MMICs are subject to reliability problems, the active elements are often the limiting factor and the major limitations have been found to be related to channel temperature. The most common failure modes can be observed via the degradation of the MMIC parameters such as I_{DSS}, gain and others (Kayali *et al*., 1996; Ponchak *et al*., 1994).

In this study, we assume all failure mechanisms obey the Arrhenius law. Thermally accelerated life tests would be effective. Mittereder *et al*. (1997) have shown the Weibull distribution is efficient for predicting the reliability of MMICs.

Corresponding Author: Fa-Xin Yu, Institute of Astronautical Electronics Engineering,
School of Aeronautics and Astronautics Zhejiang University, Hangzhou, 310027, China
Tel: +86-571-86971612 Fax: +86-571-86971797

CHANNEL TEMPERATURE

The reliability of MMICs, particularly for power devices, depends critically on the operating channel temperature. The reliability at normal operating temperatures is predicted by extrapolating data from accelerated life tests at elevated temperatures. The Weibull slope of the line depends upon the activation energy of the failure mechanism. Incorrect measurement of the channel temperature would create erroneous values of the lifetime and the activation energy. Therefore, it is important that accurate channel temperatures should be used to correlate the reliability life test data. It is obvious that the knowledge of temperatures is fundamental in obtaining accurate reliability data from accelerated temperature tests. It has been demonstrated that precise MMIC channel temperatures can be obtained by combining analytical models and physical measurement techniques.

Recently, a number of simulators have been developed (Flotherm 7.1, 2007; ANSYS 11.0, 2007) and many analytical approaches have also been given. Darwish *et al.* (2005) have proposed an accurate closed-form expression for the thermal resistance of FET structures, which predicts the channel temperature accurately.

DATA EXTRAPOLATING

To acquire MMIC reliability data in a reasonable amount of time, accelerated life test needs to be performed for the MMIC whose lifetime may be several decades. We expose the devices to elevated temperatures such that we can reduce the time to failure of a component, thereby enabling us to obtain the required data in a shorter time. The degradation rate r at which many chemical processes take place is governed by the Arrhenius equation:

$$r = A\exp\left(\frac{-E_a}{kT}\right) \tag{1}$$

where, A is a proportional multiplier, E_a is a constant of activation energy, k is the Boltzmann's constant 8.6×10^{-5} (eV/K), T is the absolute temperature in Kelvin.

The above equation has been widely used in the electronics industry. Experimental data acquired from life tests at elevated temperatures are analyzed via the Arrhenius equation to obtain the device behavior model at normal operating temperatures. The link between the lifetime data at different channel temperatures decides the accelerated factor. We can rearrange the Arrhenius equation as:

$$\ln r_{1,2} = \ln\frac{t_2}{t_1} = \frac{E_a}{k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right) \tag{2}$$

where, $r_{1,2}$ is the accelerated factor between the temperatures T_1 and T_2, t_1 and t_2 are time to failures. We can use the Arrhenius plots, from which the slope of the logarithm of failure rate versus reciprocal absolute temperature can be extracted, to estimate E_a. Extensive reliability life tests on numerous GaAs MMICs have been performed since the early 1970s. Typical measured activation energies of MMICs range from 1.2 to 2.3 eV (Mittereder *et al.*, 1997).

Empirically, as a rule, the reliability of a semiconductor device will decrease to half with every 10°C increase in the junction temperature. Mathematically,

$$\log_2 r_{1,2} = \log_2\left(\frac{t_2}{t_1}\right) = \frac{1}{T_1}-\frac{1}{T_2} \tag{3}$$

LIFE TEST METHODOLOGY

In order to analyze the life-test data properly, we should adopt a suitable mathematical failure distribution, which can be selected from several commonly used distributions, such as the normal, lognormal, exponential and Weibull distributions. It has been shown that the Weibull distribution provides better fit when many defects compete to cause failures (Mittereder *et al.*, 1997). The Weibull distribution is defined by two parameters, i.e., the characteristic life and the Weibull slope β. Its cumulative distribution function is

$$F(t) = 1 - e^{-(t/\alpha)^{\beta}} \tag{4}$$

It is obvious that with zero fails one cannot fit a failure distribution. However, Weibull and lognormal distributions provide the necessary background for establishing a reliability test methodology. The test method is described as below.

We first set a target life requirement in the field, e.g., MTTF (Mean time to failure) or λ. According to the MTTF value, we can calculate the Weibull slope value from the past collecting data. Besides the Weibull distribution, MMIC lives also yield to the lognormal distribution, thus we can get the following formula:

$$\text{MTTF} = e^{\mu+\sigma^2/2} = t_m e^{\sigma^2/2} \tag{5}$$

where, t_m is the median time. Based on the relationship between Weibull and lognormal distributions, we can get σ by

$$\Gamma(1+2/\beta)\big/\Gamma^2(1+1/\beta) = 10^{\sigma^2 \ln 10} \tag{6}$$

where, Γ (.) is the Gamma function. We then compute the characteristic parameter á$_1$ for the field using the following Eq. 7 or 8 obtained by rearranging Eq. 4 as:

$$\alpha_1 = \frac{t_m}{[-\ln(1-0.5)]^{(1/\beta)}} \tag{7}$$

$$\alpha_1 = \frac{MTTF}{\Gamma(1+1/\beta)} \tag{8}$$

At this point, the value α_2 for the test can be calculated from the accelerated factor based on Eq. 2 and 3 as:

$$\alpha_2 = \frac{\alpha_1}{r_{1,2}} \tag{9}$$

Next, the following equation is proposed to determine the required test time t_{test} with zero fails for a sample size of n, such that there is a 90% confidence that exceeds a target design value:

$$t_{test} = \alpha_2 \left(B/n \right)^{\left(\frac{1}{\beta}\right)} \tag{10}$$

where, B is the confidence multiplier for the exponential distribution.

More details can be found by Breyfogle (1972). The approach uses a transformation from the exponential distribution to the Weibull distribution such that the confidence multiplier B is also transformed. For the commonly used confidence value 90% with zero fails, we can obtain B = 2.303. In fact, the value B can be looked up from tables in standard reliability tests.

APPLICATIONS OF THE PROPOSED MODEL

Now we apply the proposed model to the following example problem: for an InAlAs/InGaAs HEMT MMIC with the sample size of 10 as depicted (Dammann *et al*., 2004), how many testing hours with zero fails are required to demonstrate an MTTF of 1×10^6 h at the operating channel temperature 125°C in the field (approximately 1000 FITs)? To solve this problem, we can select a test channel temperature and compute its corresponding acceleration factor and then use the factor in the Arrhenius model as defined in Eq. 2. Dammann *et al*. (2004) has shown that the value E_a is 1.3 eV, assume that the test channel temperature is 240°C, the acceleration factor $r_{1,2}$= 4.9×10^3 can be calculated from Eq. 2. The characteristic value á$_1$ is calculated by Eq. 7 as follows:

$$\alpha_1 = \frac{t_m}{[-\ln(1-0.5)]^{(1/\beta)}} = \frac{0.993\times10^6}{[-\ln(1-0.5)]^{(1/3)}} \tag{11}$$

Assume that the Weibull slope is 3.0 and the confidence is 90%, the required test time t_{test} can be calculated by Eq. 10 as follows:

$$t_{test} = \frac{\alpha_1}{r_{1,2}} \left(2.303/10 \right)^{(1/3)} = 140(\text{h}) \tag{12}$$

Under the above assumptions, during the 140 h life testing, if there are no failures occur, we can promise an extrapolated MTTF of 1×10^6 h at the channel temperature 125°C.

Nowadays, the failure rate of high-reliability MMICs has reached 1 FIT or less. Thus, in our experiments, we assume that the failure rate is 1 FIT. Figure 1 shows how the required test time decreases with the sample size n. From this figure, we can easily see that the sample size impacts the test time significantly. We can reduce the test time by using a large number of samples. Ideally, the accelerated life tests should be conducted with very large sample sizes. However, this is not always practical or economical. In fact, due to difficult availability of samples or test equipments, we often adopt a smaller sample size as a compromise that adversely affects demonstrating a particular reliability in the field. From Fig. 1, we can see that it is suitable to choose the sample size as 10 or more.

Figure 2 and 3 show the impact of different assumed Weibull slopes β on the required test time with all other parameters unchanged. For Fig. 2, the Weibull slopes range from 0.5 (defects) to 5 (wear out), while for Fig. 3, from 2 to 4.5. Here, the aim of Fig. 3 is to clearly show the part of Fig. 2 with slopes ranging from 2 to 4.5. From these results, we can see that the proposed approach can be appropriately used in the product inspection.

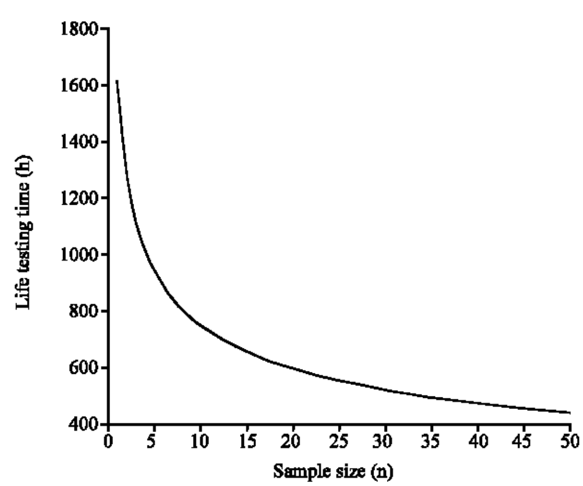

Fig. 1: Required test time vs. sample size

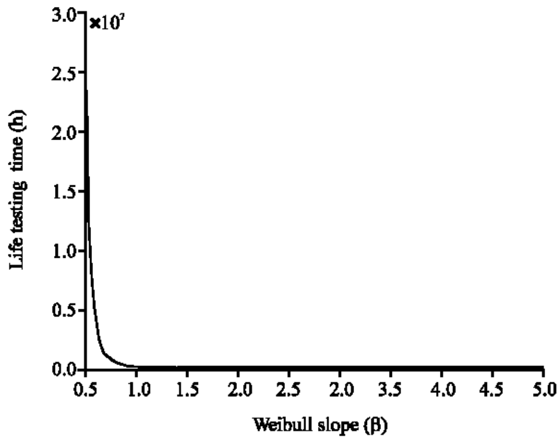

Fig. 2: Required test time vs. Weibull slope (from 0.5 to 5)

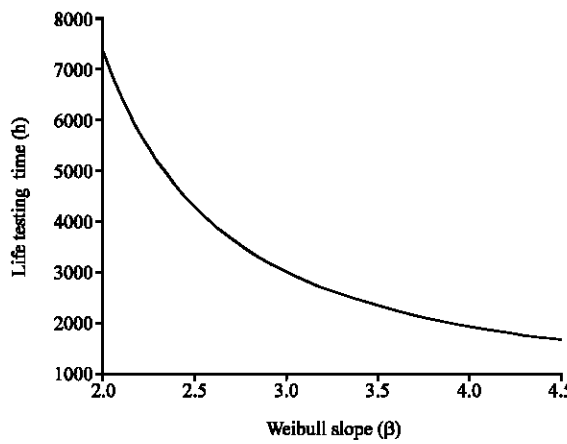

Fig. 3: Required test time vs. Weibull slope (from 2 to 4.5)

CONCLUSION

This study suggests a quick reliability test method that can be adopted by small-size industries in order to obtain the reliability figures. It is effective in improving the prediction accuracy. We strongly stress that it is seriously important to provide the reliability evaluation with the field data collection and the failure analysis of failed parts.

REFERENCES

Breyfogle, F.W., 1972. Statistical Methods for Testing Development and Manufacturing. 1st Edn., John Wiley and Sons, NewYork.

Dammann, M., A. Leuther, R. Quay, M. Meng, H. Konstanzer, W. Jantz and M. Mikulla, 2004. Reliability of 70 nm metamorphic HEMTs. Microelectro. Reliab., 44: 939-943.

Darwish, A.M., A.J. Bayba and H.A. Hung, 2005. Accurate determination of thermal resistance of FETs. IEEE Trans. Microwave Theory Techniques, 53: 306-313.

Foucher, B., J. Boullie, B. Meslet and D. Das, 2002. A review of reliability prediction methods for electronic devices. Microelectro. Reliab., 42: 1115-1162.

Gu, J. and M. Pecht, 2007. Predicting the reliability of electronic products. Proceedings of the 8th International Conference Electronic Packaging Technology, August, 2007, Shanghai, China, pp: 1-8.

Kayali, S., G.E. Ponchak and R. Shaw, 1996. Basic Failure Modes and Mechanisms. JPL Publication, California, USA.

Mittereder, J.A., J.R. Roussos, M.T. Karanikolas and W.T. Anderson, 1997. Comparison of statistical distributions for the analysis of GaAs MMIC life test data. Proceedings of the GaAs Reliability Workship, October, 1997, California, USA., pp: 54-61.

Pecht, M.G. and F.R. Nash, 1994. Predicting the reliability of electronic equipment. Proceedings of the IEEE, July, 1994, IEEE Explore, pp: 992-1004.

Ponchak, G.E., S. Kayali and H.C. Huang, 1994. he development of a GaAs MMIC reliability and space qualification guide. Proceedings of the IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium, May, 22-25, San Diego, CA, USA., pp: 69-72.