LIFETESTING GaAs MMICs UNDER RF STIMULUS

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Abstract

This paper summarizes very high temperature lifetest results on MMIC switches and attenuators designed, assembled, and screened by Motorola GEG and manufactured and tested by TriQuint. It was found that individual heating and RF bias resulted in data which indicates these devices degrade linearly with lognormal failure distributions that compare favorably with historical DC lifetesting of MMIC amplifiers. Electrical measurements indicated MESFET gate degradation was occurring, which was confirmed by failure analysis. The failure mechanism was found to be highly accelerated by temperature and is not expected to impede device lifetimes at normal use conditions for thousands of years.

Introduction

As gallium arsenide Monolithic Microwave Integrated Circuits (MMICs) mature, focus shifts from performance and manufacturability issues to factors that influence suitability in widespread military and commercial applications, like device reliability. Concerns about reliability therefore signal the move of emerging technologies from being laboratory curiosities to being inserted into systems.

There is little historical data on non-amplifier MMIC reliability. This study addresses MMIC switch and attenuator lifetesting performed under RF bias and high temperature conditions. In addition to the rare look into small signal device reliability, this investigation incorporates a test system which precisely controls temperature at the case of each device. Use of this system resulted in thermal consistency never before achieved in such a lifetest. Individual heating of the device case also allowed high frequency fixturing to be employed, which under usual circumstances would be significantly degraded by conventional oven or hotplate techniques. This new approach facilitated premium S-parameter measurements throughout the 4380-hour lifetest. The combination of precise temperature control and high quality device measurement resulted in accurate prediction of device reliability with relatively few devices.

Test Vehicles

MMICs for this study were designed by Motorola GEG and manufactured using TriQuint's ion implanted 0.5 micron depletion mode GaAs MESFET process. Recessed gates were composed of titanium/palladium/gold, as was the first layer interconnect metallization. Airbridge metal was fabricated from electroplated gold on a titanium flash. Thin film resistors were made from Nichrome, and capacitors and dielectrics were PECVD nitride.

Two types of structures have been utilized in this investigation, single-pole, single-throw (SPST) switches and voltage-controlled attenuators (VCAs). The SPST switch contains two series MESFETs with three shunt MESFETs to achieve a minimum 55 dB ON/OFF amplitude ratio and 1.8 dB maximum insertion loss. The VCA contains two series MESFETs and two shunt MESFETs, where the gate voltages control the overall attenuation. A 40 dB minimum attenuation and 28 dB of linear tuning range is required per specification.

All circuits used in this study were assembled by Motorola GEG in a metal-based, glass side-walled package, using a gold/tin eutectic die attach process, 1 mil automatic gold ball bonding, and gold/tin lid sealing. All devices were subjected to Motorola GEG's standard Class S screening which consists of internal visual inspection, temperature cycling, constant acceleration, particle impact noise detection (PIND), initial electrical testing, 240 hour burn-in at 125°C ambient, final electrical, and hermeticity tests. No samples were rejected from the production lot for failing burn-in delta requirements, as has been the case with all Motorola-TriQuint product to date.

Methodology

A set of procedures have been conducted to characterize the reliability of GaAs MMICs. These procedures are: 1) design of fixtures, 2) design of electrical measurements, 3) thermal resistance measurements, 4) accelerated life tests, 5) failure analysis, and 6) data analysis.

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Fixtures

The fixtures which house the test devices must fulfill four requirements: 1) withstand the high temperatures of accelerated reliability testing, 2) allow electrical measurements at rated frequencies, 3) provide RF stimulus and 4) allow DC monitoring by the lifetest system. Because of the unique approach of heating each device individually at the case, the requirements of high temperature fixturing was significantly reduced. An Engineering Test Fixture (ETF) was used (Figure 1). Since heat applied to the case (in excess of 260°C) was conducted out the device leads to some extent, high temperature solder was used to attach the test devices and a polyimide circuit board was utilized instead of teflon or duroid. A stripline approach was used on the polyimide, and two iterations of design and fabrication were needed to achieve a good 50 ohm match. All high temperature interface problems were addressed by device attachment and circuit board composition, so conventional high frequency fixturing could be used in the remainder of the fixturing. For example, SMA connectors and semi-rigid coaxial cable utilizing teflon dielectric could be employed without fear of melting. RF stimulus was generated within inches of each part by individual GaAs voltage-controlled oscillators. For the switch, additional broad band amplification was accomplished with a distributed amplifier MMIC. Drive levels were nominally 0.7 and 0.6 GHz at +13 dBm and 0 dBm for the switch and attenuator, respectively. The lifetest system monitored power supply voltages and currents to each device under test, as well as voltage from a detector used to measure RF power delivered through each test device.

Electrical Measurements

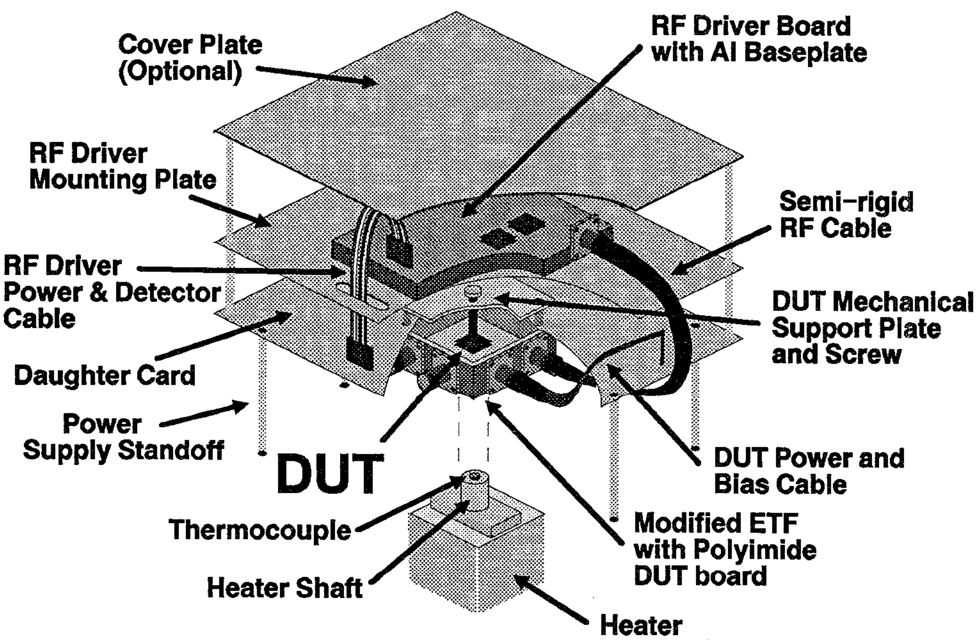
The devices were electrically characterized using an HP8510 Network Analyzer. Sixteen parameters were measured assessing the insertion loss and isolation for the switch and attenuator over their respective frequency ranges.

Temperatures & Thermal Resistance Measurements

The samples of switches were subjected to peak hotspot temperatures of 235° and 260°C and the attenuators were subjected to peak hotspot temperatures of 225° and 250°C. The temperatures were staggered for two reasons. First, if the devices failed for similar mechanisms they could be grouped for analysis. Secondly, a wider range of temperatures would give the best chance for failures to occur during the test. The temperatures were selected based on previous circuit testing and thermal analysis results. The low end of the temperature window was selected to force the widest failure distributions in time. Therefore, the highest risk was that few or no failures will occur within the six month time under test.

Determining device temperatures is a key part of any reliability study, especially if activation energies are to be determined accurately. There are several possible methods for measuring temperature, but each has advantages and significant problems. Temperatures of the entire IC package environment were evaluated from case to hotspot. For data analysis, the temperature of the failure site must be known.

Figure 1. Diagram of the Engineering Test Fixture Mounted in the Fixture Assembly.



Complete thermal analysis includes both infrared thermal imaging and liquid crystal microscopy. The data from infrared analysis, which shows how average temperatures on the die vary with case temperature and/or biasing conditions, can be combined with the liquid crystal result, which shows the precise hotspot absolute temperature, and used to predict die hotspot temperatures for a wide range of applications. Thermal measurements were made with sample devices and special thermal test chips to guarantee that the device hotspot (MESFET channel, for this study) temperatures were within 5°C of the specified absolute temperatures while being individually controlled within 0.5°C of the setpoint during the entire test.

Accelerated Life Tests

A total of four 4380 hour accelerated lifetests were conducted, two on switches and two on attenuators. The lifetests were conducted at 225° and 250°C for attenuators and 235° and 260°C for switches. Interim measurements were made at 4, 8, 16, 32, 64, 128, 256, 512, 1024, 1536, 2048, 2624, 3200, and 3790 hours. Five device samples were used at each temperature. Two measurement control devices were used for the switch and two were used for the attenuator.

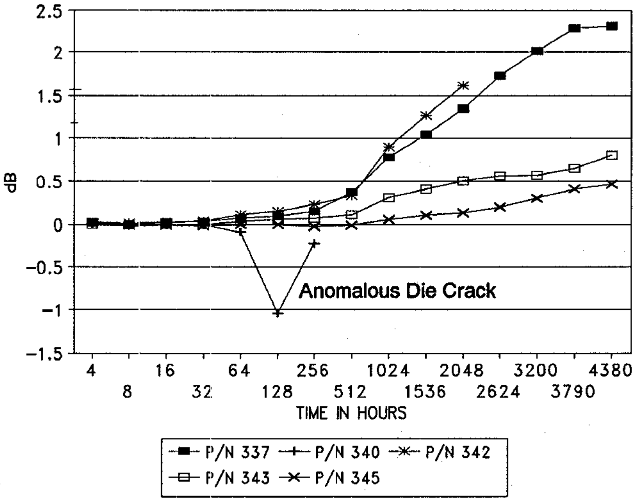
Results

Data was collected for each of the 16 electrically measured parameters at each of the 16 test points, for each of the twenty test devices and two control devices, for a total of more than 5,600 data points. The results were examined statistically (in terms of average numbers and standard deviations) and graphically. Statistical indicators showed that device measurements were extremely stable over the one year span of the electrical measurements. For control devices, variation was found to be less than 0.05 dB throughout the testing. An example of the graphical results is shown in Figure 2. Figure 2 shows the changes in S_{21}-ON for 4380 hours on switches in the 260°C lifetest. Part #340 failed at 256 hours for a cracked die which was an anomaly of the test set-up. Parts #342 and #337 degraded beyond the 1 dB failure criteria between 1024 and 1536 hours.

Failure Analysis

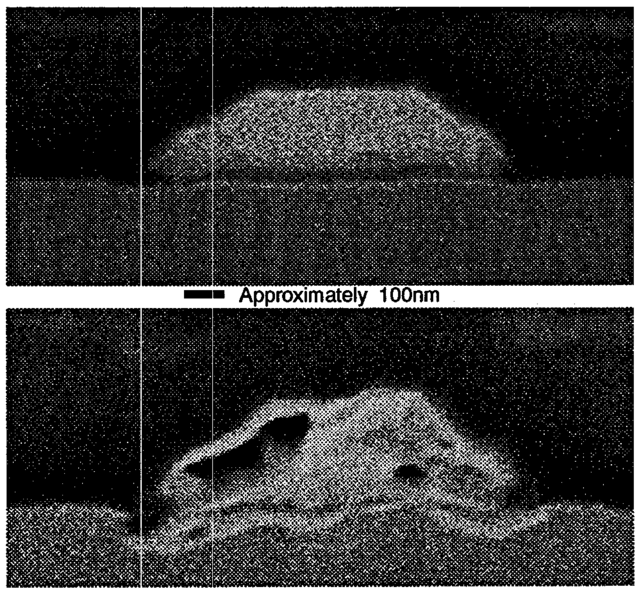
A failure analysis procedure was developed before testing began. The procedure involved many interrelated steps depending on failure modes and the relative performance of the main population of devices. Precautions were taken to confirm device degradation, and ensure a positive identification of each failure. Extensive DC measurements and Time Domain Reflectometry measurements were made on devices before decapsulation and internal inspection. The degraded devices were probed

Figure 2. Device Degradation During Testing. Change in S_{21} (ON) for Switches at 260°C.



internally after decapsulation. Each MESFET was isolated by mechanically removing air bridges. Once the degradation was assessed, the suspected gate degradation mechanism was confirmed by Focused Ion Beam cross-sectioning into the channel. The result of FIB cross-sectioning is shown in Figure 3 (reference gate on top).

Figure 3. SEM Images of FIB Cross-sections on a Reference Gate and a Degraded Gate. (45° Tilt)

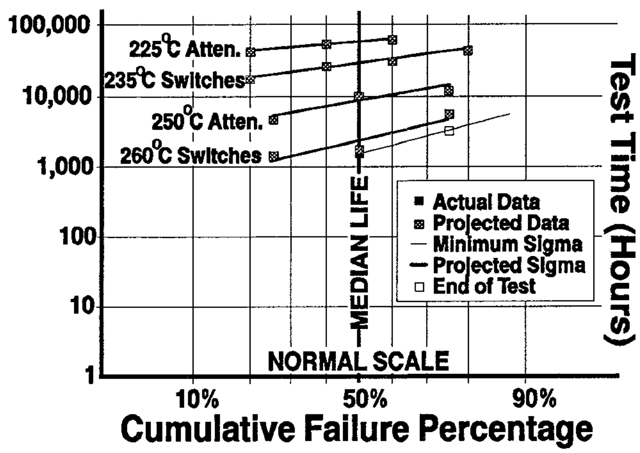


Data Analysis

Populations of devices were grouped by failure mechanism. The degradation of each device was analyzed by linear, exponential, and logarithmic methods of regression. The degradation was found to be linear.

Time to failure for each device was extrapolated or interpolated from best fit variables measurement data. Failure times for each lifetest population were determined to be lognormally distributed for all four test conditions, see Figure 4. The distribution parameters, median life and sigma, were also calculated. The lognormal distribution parameters were used to predict activation energies based on both temperatures for each part type and also for all four tests combined. The failure criteria was set at 1 dB change in insertion loss or a 5 dB change in isolation. Failure criteria of 0.5 dB and 0.25 dB were also investigated with similar results.

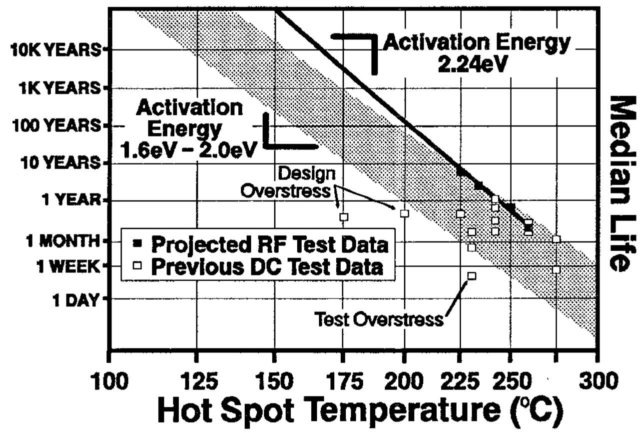
Figure 4. Lognormal Results Based on Projections of the Data.



Discussion

Although testing was conducted above 220°C for 4380 hours, only two devices degraded beyond the 1 dB failure criteria at the maximum temperature of 260°C. An additional two devices failed because of the mechanical stress required to fixture the devices. These mechanical failures resulted in die cracks which were not considered to be typical of normal device application. Despite the minimal changes that occurred during the test, projections of the degradation was possible, as well as analyses based upon tighter failure criteria. A combination of the projection and tighter failure criteria allowed for predictions of failure distributions, activation energies, and device lifetimes. Each of the four lifetests was found to be lognormally distributed. Correlation to lognormal distributions were found to be generally better than 0.9 with some correlations as high as 0.999. Lognormal sigmas (slopes) were found to be dependant on temperature and to a lesser degree, failure criteria. These effects also created a dependance of activation energy with temperature and failure criteria, as well as, some differences between device types. The activation energy ranged from 1.7 for attenuators to 2.5 for switches, both estimated with a 1 dB failure criterion. Based upon the combination of all the data, lifetimes would be expected to exceed 100 million hours at 150°C (hot spot) operation (Figure 5). These results compare favorably with previously published results. [1,2]

Figure 5. Comparisons of Results with other DC Biased Lifetests.



Conclusions

These tests indicate that high temperature lifetesing is possible utilizing individually forced temperatures while under RF bias. The precision of a monitored lifetest system heating only the device case has demonstrated that device degradation, failure distributions, and activation energy measurements can be made on small sample sizes with reasonable results. Comparison of these results to similar tests under DC bias indicate there is no significant difference between RF biased lifetesting and DC lifetesting for these types of devices. Assuming the least reliable median life at highest stress and the lowest projected activation energy, a conservative estimate of median lifetimes for the switch and attenuator, operating at 150°C peak hot spot temperature and under maximum RF bias, is 18.7 million hours or 2137 years.

Acknowledgment

Focused Ion Beam cross-sections were made by Milt Jaehnig of FEI Company, Beaverton, Oregon.

References

1. Mike Peters & Tony Rubalcava, Reliability Characterization of a Production GaAs MMIC Amplifier, GaAs REL Workshop, November 1988, Nashville Tennessee.
2. Mike Peters, Bill Roesch, & Tony Rubalcava, Studying Lifetimes and Failure Rates of GaAs MMICs, ***Microwaves and RF***, July 1988.