GaAs Reliability at High Operating Temperatures

Abstract

This document investigates the issue of GaAs MESFET channel temperature and its effect on reliability. It is shown through literature and measurements on our own process that GaAs MESFETs can operate with channel temperatures in excess of 250°C without immediate catastrophic failure. This enables *WJ Communications* to perform high temperature over lifetime testing as part of the product qualification testing of all WJ GaAs MESFET designs.

1. Introduction

Reliability at *WJ Communications* is taken very seriously. Since the early 1990's, WJ has accumulated many thousands of device hours of accelerated life tests, and we continue to do so to the present day. Accelerated life tests provide information about failure mechanisms, activation energies and failure rates.

Through high temperature accelerated life tests, it will be shown that catastrophic failure may occur at channel temperatures in excess of 270°C. It is reasonable to assume that catastrophic failure will occur at a temperature *T* where the mean lifetime of the device approaches zero hours. In the first section of this report, some of the existing literature will be reviewed about this subject; the second part discusses some of the reliability work carried out by WJ on one of our MESFET processes. From these two discussions, conclusions will be made with respect to maximum channel temperature and the subsequent implications with respect to reliability. From a MMIC point of view, it is assumed that the active device, i.e. the MESFET, is the limiting factor.

2. GaAs MESFET Failure Mechanisms

GaAs MESFET reliability data has been extensively reported in literature [1,2,3]. The main failure mechanisms involve gate metalization, Schottky contact, and source/drain ohmic contacts, with the dominant failure mode being channel related.

Two examples are as follows:

(a). Metal migration is the movement of metal atoms due to being pushed by high-energy electrons. This is a high current density and temperature effect. Metal migration life tests are generally carried out at temperatures in the region of 250°C ambient [2].

(b). Burnout is the partial or complete melting of a large device area resulting in catastrophic failure. Gate-to-Drain burnout is considered to be the result of a combination of other failure mechanisms leading to avalanche breakdown and hence will be dependent on surface characteristics and device layout. To improve the breakdown voltage and burnout characteristics of MESFET devices a recessed gate is usually employed. This is done with WJ devices. Source-to-Drain burnout has been found to be thermally activated and has been shown to start near the drain side where current crowding causes hot spots which induce thermal runaway in the buffer or substrate. However, this has been shown to occur only when the channel and buffer temperatures reach 550°C [3].

2.1 Reported Thermal analysis Techniques

The reason for such high temperature life tests is that most physical/chemical processes can be accelerated with temperature at a rate correlated to a constant: the activation energy. Normal thermal analysis techniques include infrared, liquid crystal and modeling. Infrared measures average chip temperature, and the liquid crystal technique can measure and pinpoint hotspots. MESFET failure mechanisms have been found to follow the following Arrhenius equation [2]:

$$FT2 = FT1 * \exp(Ea *(1/T2-1/T1)/k)$$

Where

FT1,2 = time to failure at temperature (°Kelvin)
Ea = activation energy (eV)
K = Boltzmann's constant = 8.6E-5 eV/K

A further expansion of this equation can be used to approximate median life (Tm) at any channel temperature [2]:

$$Tm = Tmo * \exp(Ea/kT)$$

Where

Ea ~ 1.8eV for general GaAs MESFET devices
k = 8.6E-5eV/K
T = Temperature in Kelvin
Tmo = 9.11E-15 for MESFET

An approximation to the average mean time to failure is given by [2]:

$$MTTF = Tm * \exp((\sigma\hat{}2)/2)$$

Where

MTTF = Average mean time to failure
Tm = Median time to failure
σ = Log – normal standard deviation

It can be concluded from the above information that MESFET reliability and channel temperature are strongly linked and in fact under normal RF and DC conditions the channel temperature can be in excess of 250°C without causing instantaneous catastrophic failure. The temperature at which this occurs can be approximated as when the MTTF approaches zero hours. It is safe to assume that a conservative maximum channel temperature would be 250°C for most MESFET processes. Fig 1 shows actual data taken on a Triquint MESFET device [4] where the maximum channel test temperature was 305°C.

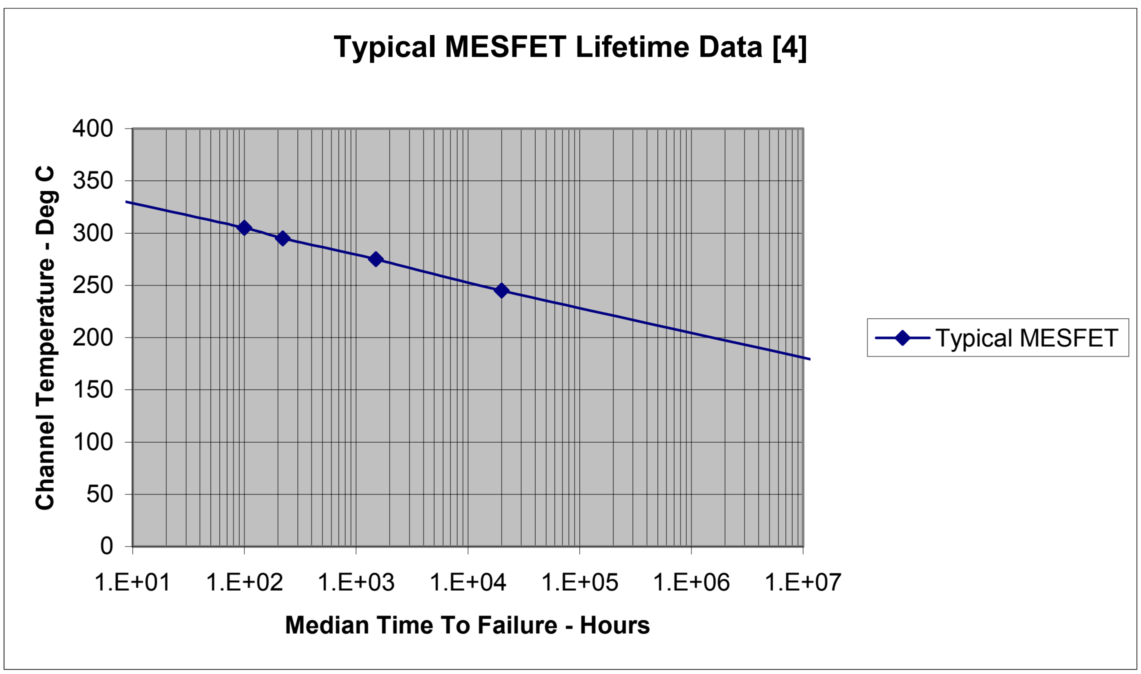

Figure 1. Typical Industry Standard MESFET Life Test Data [4]

3. GaAs Reliability at WJ

To increase the understanding of device lifetime performance, WJ has conducted extensive RF testing of representative devices and complete life tests of each major element making up FET's and IC's. These thorough characterizations of products and processes have allowed WJ to become a dependable supplier of high quality GaAs devices. The following sections describe just some of the tests WJ has performed in the past and their results. These tests are specifically identifiable with the high temperature life performance of our MESFET devices.

3.1. MMIC Reliability under RF Drive

The most accurate way to measure MMIC reliability is by performing accelerated testing under worst case operating conditions (dc and RF signal levels) for a given device type. Due to the physical limitations of the packages and connections used, this test was limited to an ambient temperature of 175°C. This test was designed to provide confidence in the reliability of the product under test. The devices in these tests were cooled to room temperature at "200 Hour" intervals and characterized across their operating frequency band.

Test Structure: Uses fully functional MMIC's of various types in a Kovar housing with SMA connectors. The MMIC chips were brazed onto a metal rib using AuSn. Alumina substrates were used for input and output transitions.

Parameter Monitored: RF gain, dc current.

Failure Criteria: 1.0dB change in RF gain.

Results: Table 1 summarizes test conditions and result

Device Type	Sample Size	Ambient Temp	RF Input	DC Bias	Total Hours	Number Failed
FA04A	12	175°C	5 dBm	5V	3821	0
FA04A	12	175°C	5 dBm	5V	1000	0
FA04A	12	175°C	5 dBm	5V	1000	0
FAS01A	4	175°C	7.5 dBm	5V/-3.75V	1500	0
FAS01A	8	175°C	7.5 dBm	5V/-3.75V	1000	0
FA03B	6	175°C	10 dBm	11V	1000	0
FA03B	11	175°C	10 dBm	11V	1200	0
FA03B	8	175°C	10 dBm	11V	1000	0

Table 1. RF Life Test Data

Device Type	Description
FA04A	0.5GHz to 3.0GHZ 2-stage feedback amplifier
FA03B	2.0GHz to 8.0GHz 2-stage feedback amplifier
FAS01A	X-band 2-stage LNA with switch attenuation

Table 2. Device Descriptions

Conclusions: These tests did not uncover any failure mechanisms due to excessive channel temperature which were calculated using a computer model to be 203°C

3.2. FET Life Test

In order to perform tests at higher temperatures, dc-only tests are carried out. This test is sensitive to ohmic and Schottky contact, the state of the channel, and the GaAs surface and has been performed at WJ since 1982 to evaluate and qualify new processes. Testing performed since 1990 has been carried out at ambient temperatures up to 260°C.

Test Structure: The test structure uses a MESFET brazed to a Kovar carrier using a thin-film alumina substrate to provide a self-biasing scheme with bias level set at approximately Idss/2.

Parameter Monitored: DC bias current Ids.

Failure Criteria: 10% change in Ids.

Results: Table 3 summarizes the test conditions and results.

Device Type	Sample Size	Ambient Temp	DC Bias	Total Hours	Number Failed
F200H MESFET	8	220°C	50% Idss	2390	0
F105R MESFET	12	220°C	50% Idss	1751	1

Table 3: MESFET DC Life Test

Failure Mechanism: The one failed unit exhibited ohmic contact degradation.

Conclusion: This test clearly shows that these devices can suffer an ambient temperature of 220°C without channel breakdown. For this test an actual channel temperature of 259°C was derived using a computer modeling techniques program assuming that most of the MESFET's power dissipation occurs under the gate at the drain end.

4.0. Summary

A considerable amount of work has been carried out in the area of reliability of GaAs MESFET devices [1,2,3,4]. The common approach by all manufacturers of GaAs MESFET devices and indeed all other semiconductor devices is to put in place a form of accelerated life test. For the purpose of MESFET reliability prediction, high temperature operating life test is very widely used under dc and RF operation. This is the approach WJ has taken for all our GaAs processes. All of the data discussed in this document comes from operating life tests both at WJ and as reported in literature. The theoretical model equations were taken from reported literature. The literature has shown that GaAs MESFET devices are comfortable working at channel temperatures in excess of 250°C without immediate catastrophic breakdown, albeit having much lower lifetimes. Therefore considering the reliability work carried out on the WJ process, a very conservative absolute maximum channel temperature where catastrophic failure occurs can be assumed at 220°C.

References

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