# Humidity Resistance of GaAs ICs

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**Abstract -- A series of investigations into reliability effects of moisture on GaAs structures have lead to the conclusion that GaAs devices have resistance to degradation effects of humidity. This not only provides evidence that GaAs devices are ready for low-cost non-hermetic packages, but that GaAs ICs may have superior reliability performance compared to silicon devices under accelerated humidity conditions.**

## 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 packaging solutions. To survive in plastic and other non-hermetic packages, GaAs ICs must have resistance to humidity. This work describes a complete set of environmental stress tests used to qualify the reliability of integrated circuits in plastic packages, as well as, two special tests used to investigate moisture resistance.

## Procedures and Results

The qualification tests of low cost packages provide a basis for reliability investigation. Completion of standard tests sets do not usually provide insight into types of failure mechanisms, failure distributions, or activation energies. This study provides data that standard test sequences can be completed successfully and that GaAs devices can pass more rigorous tests, particularly relating to moisture. Moisture degradation is a primary concern for plastic encapsulation and for operation in non-hermetic packages.

### *A. Standard Testing*

The standard test set performed in this study involved the completion of all package-related tests outlined in JEDEC-STD-26A: General Specifications for Plastic Encapsulated Microcircuits for Use in Rugged Applications.

1) Sample Description. The test vehicle used to conduct the standard testing was a SPST switch with a built-in driver. The material used for encapsulation is an epoxy transfer mold compound manufactured by Nitto (Nitto part #MP-X-180), with a glass transition temperature of 160°C. The lead frame is made of a copper alloy, (Olin 194 ST/RA) with spot gold plating and 60-40 solder plating on the leads. The finished device has a gull wing lead configuration for SMT applications.

2) Test Description. The tests performed were: physical dimensions, marking permanency, solderability, autoclave, lifetest, humidity test, lead integrity, resistance to soldering heat, thermal shock, and temperature cycling. The only two exceptions to the specification were that the lifetest and humidity test were performed without bias. Because the package was a custom quad 20-pin, attempts to socket and bias the IC resulted in shorting of the leads, so unbiased testing was mandated. To counteract the thermal effect of testing without bias, the lifetest was operated at 150°C ambient, which is 25°C hotter than 125°C ambient stated in the specification. Both the plastic package and the die were therefore exposed to greater temperatures in this unbiased version of the lifetest. This hotter condition is more stringent than biased testing at lower temperatures since GaAs failure mechanisms are primarily accelerated by temperature. In an unbiased humidity test, the moisture is allowed to saturate the plastic and penetrate completely to the die surface. Whereas in a biased test, the heat that is generated on the circuit tends to drive the moisture away. Bias is not as an important accelerating condition in humid environments for gallium arsenide devices as it is for silicon circuits since the GaAs metallization system is primarily gold and corrosion is less likely than when IC interconnections are formed of aluminum. Both life and humidity tests exceeded the minimum specified 1,000 hours (1,500 hours was conducted).

3) Test Results. All testing was completed without experiencing a failure.

### *B. Sealing Moisture Inside*

To provide data showing that the 5,000 ppm moisture limit set for hermetic packages is not applicable to GaAs devices, a special "worst case" test was developed and completed. During this new test, combinations of extra water and extra epoxy (which can outgas water vapor under some conditions) were purposely introduced into the package cavity prior to seal. The devices were first cooled to -20°C for about 30 minutes in an unbiased mode. This step was designed to condense all the moisture on the cavity and die surfaces inside the package. Then the devices were powered and forced to 80°C for a 15 minute dwell. The power was removed from the devices and they were frozen again.

Twenty-one 132-pin devices were run in this test for 1000 cycles without any failures developing. The samples were measured at interim points of 100, 200, and 500 cycles using a product testing sequence which conducts 129 functional and parametric evaluations. After completing the test, most of the samples were submitted for residual gas analysis. The devices that had extra water and epoxy inside the package could not be measured since they swamped the instrument with moisture, but the test lab estimated that at

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least 20% moisture was inside the package. The samples were then examined optically at high power. No anomalous defects or changes to the die surfaces were observed.

**Table 1. Standard Test Results, Custom 20 Pin Plastic Package.**

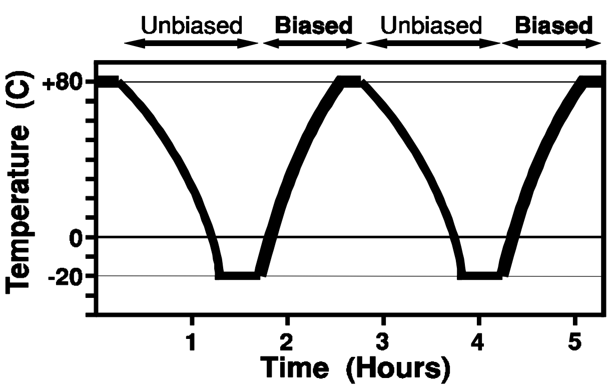
| # | Name | JEDEC STD 22 Method | Sample Size | Failures | Detail |
|---|---|---|---|---|---|
| B1 | Physical Dimentions | B100 | 2 | 0 | Verify Data Sheet |
| B2 | Marking Permanency | B107 | 4 | 0 | View @ 5-7 inches, 3X magnification |
| B3 | Solderability | B102 | 25 | 0 | 260°C, 5 seconds |
| B4 | Autoclave | A102 | 100 | 0 | 2 atm, 121°C, 100% RH, 96 hours |
| C1 | Lifetest | A108-A | 77 | 0 | 150°C, 1500 hours, unbiased |
| C2 | Humidity | A101 | 77 | 0 | 85/85, 1500 hours, unbiased |
| D1 | Lead Integrity | A105-A | 25 | 0 | 8 oz tension & bending stress |
| D2 | Resistance to Soldering Heat | B106 | 22 | 0 | 260°C, 10 seconds |
| D3 | Thermal Shock | A106 | 77 | 0 | -40°C to 125°C, 100 cycles - Liquid |
| D4 | Temperature Cycling | A104 | 77 | 0 | -40°C to 125°C, 100 cycles - Air |

1) Sample Description. The test vehicle used to conduct the series of tests is a digital LSI custom ASIC in a 132 pin multilayer ceramic cavity package. The die attach material is epoxy and the lid is sealed with solder, resulting in a hermetic package. Assembly and encapsulation of these packages was accomplished in TriQuint's Beaverton assembly facility. Twenty-five sample devices were drawn from finished goods inventory. Six devices were left intact. Fifteen devices were delidded carefully. An extra drop of die attach epoxy was added to the inside of the lid of five devices and they were re-sealed with solder. An extra drop of epoxy and an extra drop of water was added to 10 devices and they were re-sealed. All of the devices were submitted for fine and gross leak testing and found to be sealed correctly without any detectable leaks. Four devices failed the initialization process, and were removed from this test. The test samples were measured initially and at every interim point using the standard production test. The electrical test included 129 functional and parametric measurements on each device. A device was considered a failure if it did not meet the test limits on any one of the individual tests regardless of the magnitude of the change involved. In other words, a device could be considered a failure if it was initially near the edge of a specification limit and a slight change or measurement shift occurred which resulted in the device being outside the limit. There were no delta limits or guard bands in the testing. Changes in the devices during the test (primarily from bad to good) indicate that test repeatability and reproducibility may be the cause for most of the initial "failures" and their subsequent recoveries. Although all devices were known to be passing when submitted to finished goods inventory, six of the 21 samples were failures after the delidding and moisturizing procedure, including three devices which were not delidded. Two of the six "bad" devices were selected as control devices, and the other four "failures" were allowed to run as normal devices. The devices which failed electrical measurements at the start of the test were included in the testing to see if they would recover or otherwise change in terms of the degradation that caused them to be categorized as failures. In all, five devices were used as controls, including the two that were initially failures. The control parts were selected from each preparation group and measured initially and at each interval, but they were stored unbiased at room ambient conditions during the cycling of the other devices.

2) Test Description. Since moisture is the main focus of this test, conditions were selected to exacerbate any effects of the water which was purposely added to the devices. It was not known how much water remained in the package cavities after re-sealing, so a test was developed to ensure that moisture would condense on the die surface. The moisture was condensed by first cooling the devices in an unbiased mode. Based upon the least favorable amount of water, and a reduced pressure inside the cavity, a few degrees above freezing was expected to be adequate to reach the dew point inside the package. To ensure that the dew point was reached, the test devices were exposed to -20°C for about 30 minutes in an unbiased mode. After the condensing temperature, the devices were biased. This step would then guarantee both moisture and bias at the die surface for at least a few moments while the die heated-up. The ambient temperature was then forced to 80°C and held there for about 15 minutes. This cycle allowed the devices to be running in a biased mode for approximately half of the test time, so that any electrochemical reactions would have adequate time to take effect. Eventually, the bias was removed from the devices and they were frozen again. The entire cycle was about 2 hours and 40 minutes long, so that the 1000 cycle duration included well over 1000 hours in a biased mode, and approximately 1000 hours with moisture condensed at the die surface. The combination of moisture on the die,

bias, and accelerated temperatures was selected to provide an environment conducive to corrosion. The test conditions are shown graphically in Figure 1. After the initial measurements, the test was run for 1000 cycles with a final measurement at the end. There were also interim test points after 100 cycles, 200 cycles, and 500 cycles. Each interval was intended to run uninterrupted, but several problems occurred with the test chamber during the test and there was significant down time during the first three intervals. The final 500 cycles ran without an unscheduled break. In general, the electrical measurements were all made within 48 hours of the completion of each test interval. Three parts were remeasured at the completion of the test because of errors made in the measurement procedure. The initial measurements began in April of 1991, the testing ended in May of 1992, and the residual gas analyses and internal inspections were completed on sample devices in September 1992. The water vapor content found inside each type of sample is shown in Table 2.

**Figure 1. Thermal Cycle Profile.**




3) Results. The 21 samples were measured initially and at four time points during the testing. Nine of the 21 samples were measured with the same results at every test point. One additional device that initially measured "bad," remained "bad" at every test point. There were five devices that measured good most of the time, and finished the test without any problems, but did "fail" at one of the first two interim timepoints. There were four devices which initially registered as "failures" but passed all of the last three or four test points. And there was one device which started as a "failure," then measured good at the first two time points, and finally finished as a "failure." Of all the 84 opportunities for devices to change from good to bad or bad to good, there were 16 changes. In all, none of the 15 devices that started the test good, failed the test. Four of the six devices that were "bad" at the start changed to good devices during the testing. Twelve of the 21 devices were submitted to an outside test lab for Residual Gas Analysis and internal water vapor content measurements per MIL-STD-883, Method 1018, procedure 2. Of the twelve devices submitted, only five analyses were successfully completed. Three of the no test results were caused by improper punctures and another failed because of improper preparation. The remaining three null results were caused because the moisture inside the package "swamped" the analysis machine. The test lab personnel estimated that at least 20% moisture was inside the package to cause the effect they observed. Nearly all of the devices were fully delidded and examined optically at magnifications up to 1500X. No foreign materials, staining, corrosion, or anomalous effects were observed during the inspections on any of the devices. No differences were observed between intentionally moisturized devices which had been cycled, and devices coming directly from finished goods inventory.

**Table 2. Residual Gas Analysis Results.**

| Sampl e | Type | Moisture (ppm) |
|---|---|---|
| #20 | Normal | 18,100 |
| #23 | Normal | 18,700 |
| #25 | Normal | 19,200 |
| #3 | Extra Epoxy | 33,600 |
| #4 | Extra Epoxy | 64,400 |
| #9 | Extra Epoxy & Water | >200,000 |
| #10 | Extra Epoxy & Water | >200,000 |
| #16 | Extra Epoxy & Water | >200,000 |

*C. Reliability Without Hermeticity*

An additional worst case test was designed to specifically evaluate the GaAs technology in humid environments with minimal interactions of any particular package style. A special Technology Characterization Vehicle (TCV) was selected to provide the maximum number of independent active devices, so that various bias conditions could be investigated in humidity. The TCV was tested without any lid. The packages were biased while in a test chamber providing an 85 °C environment with 85% relative humidity. To reiterate, the die were completely exposed to the high humidity and high temperature while biased for the duration of the test. The samples were tested for 1,000 hours with 3 interim test points. The devices survived without failure or significant degradation in DC parameters.

1) Sample Description. The TCV was a 7 x 7 FET array designed on a 60 mil square die. All the FETs were depletion mode with measured pinch-offs at about -800mV. Each FET in the array had a 1 um long by 50 um wide gate. The FETs were connected with common drains and sources in columns using first layer metal. The gates were connected in common by rows of

airbridge metal. The TCV was packaged in an industry standard Dual In-line Package (DIP) using conductive epoxy without any lids. The array design allowed 49 FETs to be measured in a DIP package with only 24 leads.

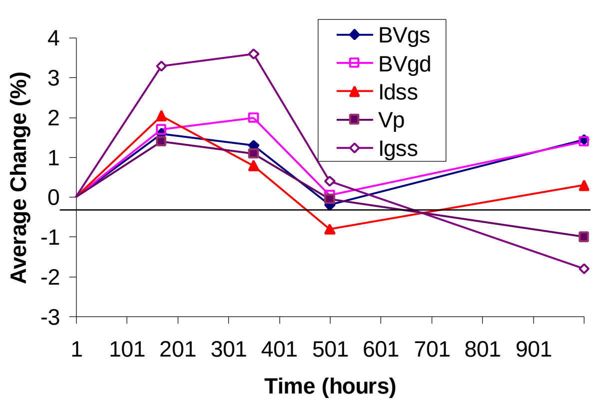
2) Test Description. Six packages were biased while in a test chamber providing an 85 °C environment with 85% relative humidity. Four different lifetest bias conditions were selected. In all cases, the source was grounded. The conditions were: 1) no bias, 2) Idss; gate = 0 V, Drain = 3 V, 3) reverse biased with the gate at -2 V and source and drain grounded, and 4) pinchoff with the gate reverse biased at -2 V with drain at +3 Volts. The bias settings are shown in Table 3. Idss was the only condition dissipating significant power. Each FET at Idss dissipated approximately 9 mW, for a total of 81 mW on each entire array. The samples were measured at interim points of 168, 336, and 500 hours using an automated electrical measurement system which conducts parametric tests. Channel current (Idss), Pinchoff (Vp), Gate Leakage (Igss), Gate-Source Breakdown (BVgs), and Gate-Drain Breakdown (BVgd) were measured initially and at each test point.

**Table 3. FET Array Bias Conditions.**

| State | Gate | Drain | Source | # of FETs |
|---|---|---|---|---|
| No Bias | 0V | 0V | 0V | 12 |
| Idss | 0V | 3V | 0V | 9 |
| Reverse | -2V | 0V | 0V | 16 |
| Pinchoff | -2V | 3V | 0V | 12 |

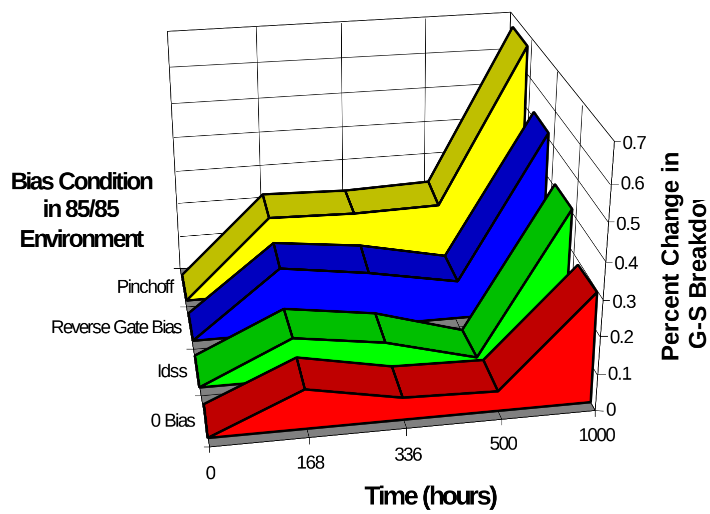
3) Test Results. In all, 294 FETs were tested for 1,000 hours. The devices survived, and exhibited minor changes in DC parameters. Idss decreased less than 2%, Pinchoff moved positive less than 5%, gate leakage increased less than 5%, and breakdowns increased less than 5%. Some differences were noticed in these results due to the various lifetest biases.

**Figure 2. Changes for FET Arrays Directly Exposed to 85°C/85% Relative Humidity.**




In particular, gate leakage improved (decreased) under reverse bias. The increases observed in breakdown voltages are considered "improvements." There were no significant changes by FET or FET grouping and no change (either improvement or degradation) over 20% was detected.

**Figure 2. Lack of Change During Test. Improvement in Breakdown Example.**




## Discussion

The results of these tests demonstrate the resistance of GaAs IC technology to reliability degradation caused by humidity. Two worst-case scenarios were used to show complete immunity to high humidity environments. Additionally, typical moisture evaluation testing was demonstrated as part of an industry standard set of package-related qualification tests.

## Impact

The results of this work clearly demonstrate acceptable humidity performance of GaAs IC technology. This not only provides evidence that GaAs devices are ready for low-cost non-hermetic packages, but that GaAs ICs may have superior reliability performance compared to silicon devices under accelerated humidity conditions.