

# High Temperature, High Power RF Life Testing of GaN on SiC RF Power Transistors

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## *Abstract*

*As GaN power device technology matures and gains acceptance in the market place, suppliers who provide products using this promising technology must prove its reliability. This paper will provide an overview of the testing approaches used to establish failure rates and will provide a comparison of DC and RF based HTOL methods. The primary focus of this paper will be the high power RF HTOL test method used by M/A-COM Technology Solutions to qualify its new MAGX line of discrete GaN on SiC RF Power Transistors. An overview of the results and a comparison of the reliability of GaN with respect to older silicon based power semiconductor technologies will be discussed.*

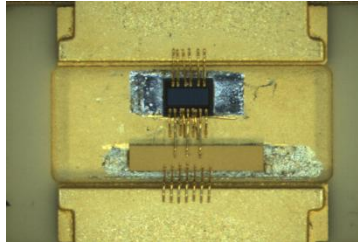
It is clear that Gallium Nitride on Silicon Carbide based semiconductor devices for RF power amplification are rapidly gaining acceptance in the RF and Microwave industry. The promise of the technology to provide high power density and high efficiency, as well as operate over large percentage bandwidths while supporting higher channel temperatures as compared to previous semiconductor technologies, is finally coming to fruition. All technologies proceed through a uniform progression; introduction, mainstream acceptance and adoption and ultimately onto technology obsolescence. However, before any new technology can be fully accepted and adopted its reliability must be proven. Further, the current market environment that demands short design cycles also demands reliability. The world class semiconductor manufacturers of today understand this and thus routinely subject their new products to extensive reliability and quality screening.

M/A-COM Tech's RF Power Products Group in Torrance, CA has a long and respected history of providing high quality, reliable RF and Microwave power device solutions for commercial and military applications extending back to the early 1970's. M/A-COM Tech developed a wide variety of systems during this period stretching from UHF through S-Band for military and commercial communications, primary and secondary air traffic control radar, avionics, satellite uplink and industrial and medical applications, many of which remain in production today. The devices designed into these systems required rigorous qualification and/or reliability screening, as a critical component in establishing an overall lifetime prediction for these mission-critical, high reliability systems. As a result, M/A-COM Tech has deep experience in designing and testing components that can support 30+ year system operational lifetimes.

M/A-COM Technology Solutions has recently introduced a new line of 0.5μ gate Gallium Nitride on Silicon Carbide (GaN on SiC) based RF power transistors and true to our heritage,

subjected the technology to exhaustive reliability and quality testing. This paper will describe the process applied and summarize the results of that testing.

Figure 1. 30W CW HEMT



For the purposes of qualifying the line of MAGX GaN on SiC power transistors, a 30W non-internally matched transistor design was chosen (ref figure 1). The device is significantly larger than those manufacturers typically select for qualification and reliability testing. Smaller unit cell configurations on the order of a few tenths of a millimeter are more common, however; M/A-COM Tech's approach of using a larger, higher power semiconductor was selected because we believe it represents a direct product design to be offered to the market, rather than just a "slice" of a device. The semiconductor itself is 6mm gate periphery HEMT mounted in a ceramic package using Au/Sn eutectic solder. Package to device interconnects were accomplished using standard 2 mil Au gold wire bonding techniques. The qualification and reliability testing were broken into two major sections: packaged product testing, which consisted of MIL-PRF-19500 based Groups A, B and C screening of the packaged transistor product, and the high power, high temperature RF life test that focused on the reliability of the GaN power semiconductor chip itself. Each screening section was conducted on a separate population of devices. The intrinsic semiconductor testing (RF HTOL) is the main focus of this paper, however; Table 1 outlines all of the reliability screening testing performed to qualify the product.

Table 1

<b>Population 1 MIL-PRF-19500 Packaged Product Screen</b>	<b>Population 2 RF Power High Temp Operating Life</b>
Internal Visual RF and DC tests Solderability Resistance to Solvents Temp Cycle Hermetic Seal (gross leak) Bond Strength Terminal Strength Moisture resistance Shock Vibration Constant Acceleration Salt Atmosphere Burn-in (Intermittent Operating Life)	Internal Visual Ultrasonic die attach inspection RF and DC tests IR Scan Capping Hermetic Seal (Gross Leak) RF HTOL

A significant number of transistors were built across multiple wafers and wafer lots. This population was subjected to the Population 2 screening tests of Table 1 which included internal visual, ultrasonic die attach inspection (to eliminate attachment voids as a significant variable), and functional DC and RF testing. A sample of 5 devices from that group was subjected to Infrared Scanning using a Quantum Focus Infrascop II system to determine the characteristic thermal impedance. This information was used to develop the following equation for calculating the channel temperature of the devices in the burn-in system:

$$T_{CH} = P_{DISS} \times (2.932 + 0.01973 T_{SURFACE}) + T_{SURFACE}$$

Where:  $T_{CH}$ =DUT Channel Temperature,  $P_{DISS}=P_{dc}-P_{out}+P_{in}$ ,  $T_{SURFACE}$ =Heat Stage temperature, and  $\Theta_{jc}=2.932^{\circ}\text{C/W}$

A total of eighteen devices including the 5 parts that were IR scanned were then selected to undergo the RF HTOL. The drain voltage was set to 50V and the gate voltage was adjusted to set a quiescent current of 250mA. RF power was applied at 2.5WCW at a frequency of 3 GHz. The drain and gate voltages were held constant over the course of the test. The three populations of devices were run at constant channel temperatures of 290°C, 305°C, and 320°C, respectively. Over 16,000 cumulative hours of data were collected in total over the course of the testing. The devices at the lowest temperature ran for over 1,600 hours on an individual part.

At regular intervals during the test, the high temperature stress was paused and a series of DC and RF characterization measurements at 60°C were performed on each DUT. The purpose of these tests was to verify the degradation rate observed at temperature is consistent with the performance degradation at normal operating temperatures.

The failure criteria for the test was defined as either a 1dB drop in the RF output power of the DUT or a 20% drop in the operating drain current during the test. At the elapsed time where one of these two instances occurred, the part would be considered as a failure. Over the course of the testing, it became clear that 1dB drop in RF output power consistently occurred before the drop in drain current. For this reason, it was designated the primary failure criteria going forward. For devices that did not reach the failure criteria during the duration of the test, the failure time was determined from curve-fitted extrapolation techniques. A sufficient amount of data was available in each case to establish a good curve fit for the extrapolations. As a result median lifetimes for each temperature population were calculated and may be found in Table 2.

Table 2: RF Life Test Median Life Results Based on 1dB Drop in RF Output Power

	Hours	$T_{CH}$
<b>ML</b>	<b>529</b>	<b>320°C</b>
<b>ML</b>	<b><math>1.5 \times 10^3</math></b>	<b>305°C</b>
<b>ML</b>	<b><math>3.7 \times 10^3</math></b>	<b>290°C</b>
<b>MTTF</b>	<b><math>5.3 \times 10^6</math></b>	<b>200°C</b>

\*Data for 290°C is extrapolated

As mentioned earlier, conducting life testing of such large periphery device is not typical and there is limited data available to the public covering three-temperature elevated reliability tests of such GaN HEMTs. The majority of life testing conducted to date was done using multi-temperature DC bias only, with no RF energy applied to the devices. Therefore, it is difficult to compare these results to other manufacturers' results. However, the projected lifetimes compare well with what has been reported for the limited activation energies ( $E_a$ ) found. Additionally, this campaign is one of the few known studies to use a thermal-impedance value obtained from measured IR results under high RF output operation. It is important to note that this accurately depicts the channel-temperature value at the exact elevated temperature test settings. This test program is believed to be more accurately and rigorously supported as to the predicted median-life than any campaign reported for devices of this size and power level.

The graphs of RF output power degradation (Figures 3-5) show a common trend where there is an initial drop in performance over the first 100-200 hours. Subsequently, the performance levels off showing significantly less degradation over time. This could point to two different mechanisms within the device that may cause performance degradation. Interim test results run at 60°C at regular intervals during the life test indicate performance degradation consistent with that as shown in Figures 3-5. The lognormal cumulative distribution plot is found in Figure 6. The corresponding Three-Temperature Arrhenius plot used to extrapolate to lower operating temperatures is found in Figure 7. From the data an activation energy of  $E_a=1.77$  was calculated.

These results are considered applicable to M/A-COM's entire family of GaN HEMT products. The next and very important step is to subject the devices that underwent this RF HTOL testing to detailed scrutiny and analysis to attempt to determine the specific drivers of device failure in the semiconductor. In Silicon based high power semiconductor devices, the primary and generally accepted failure driver, although not necessarily the only one, has been related to failure due to metal migration. Activation energy of around  $E_a=1$  has been used in conjunction with Black's Equations for metal migration for the purposes of predicting MTTF in M/A-COM Tech's SiBJT devices.

The testing described in this paper presents data confirming the long term reliability of products manufactured with M/A-COM Tech's Gallium Nitride on Silicon Carbide semiconductor technology and operated under RF compression at rated bias conditions. The results are consistent with the quality and reliability of the products manufactured over the last 30 years by M/A-COM Technology Solutions RF Power Products Group. Qualification reports covering the MIL-PRF-19500 screening as well as the RF HTOL testing described here are available on request.

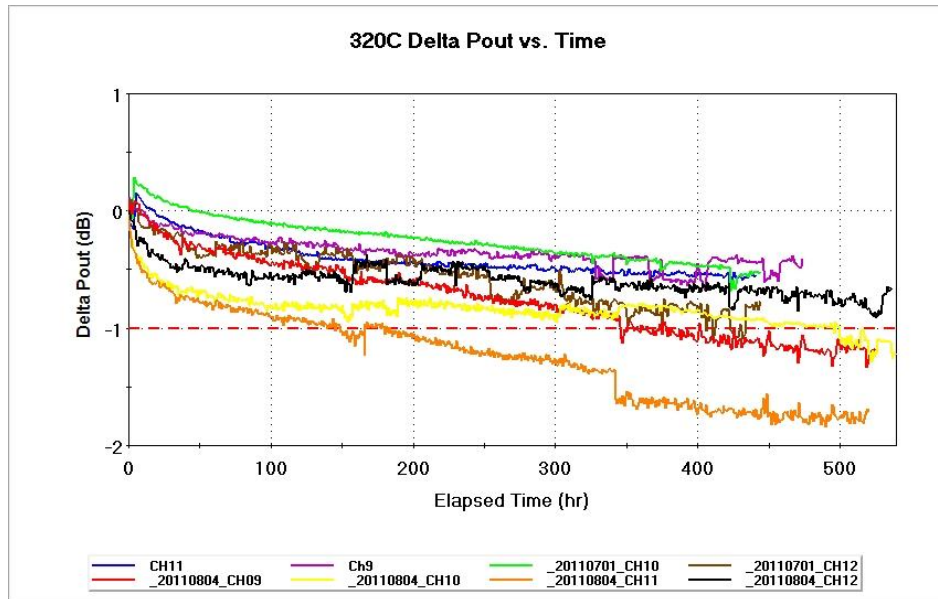


Figure 3 - RF Output Power vs Time for Channel Temperature of 320°C

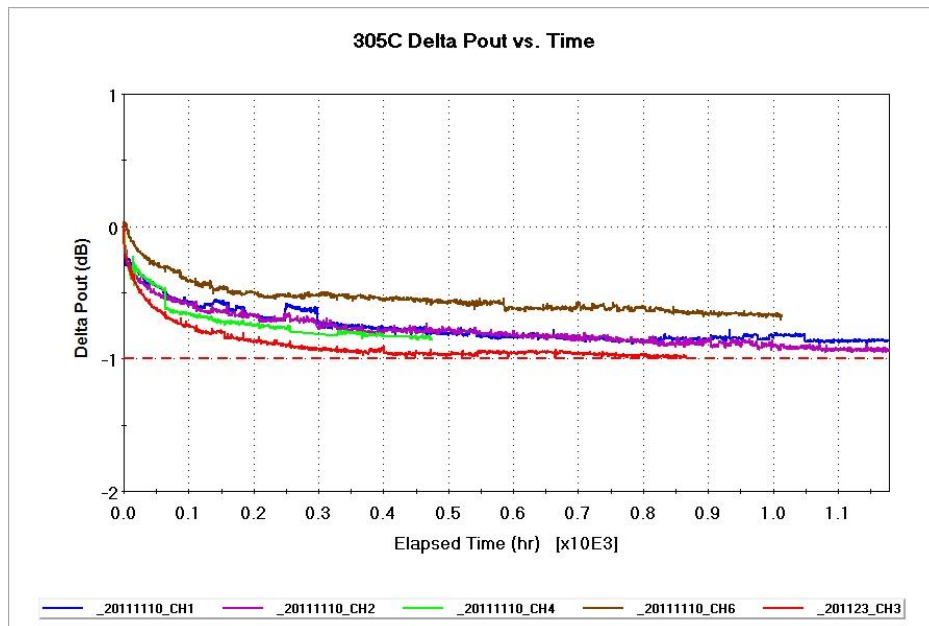


Figure 4 - RF Output Power vs Time for Channel Temperature of 305°C

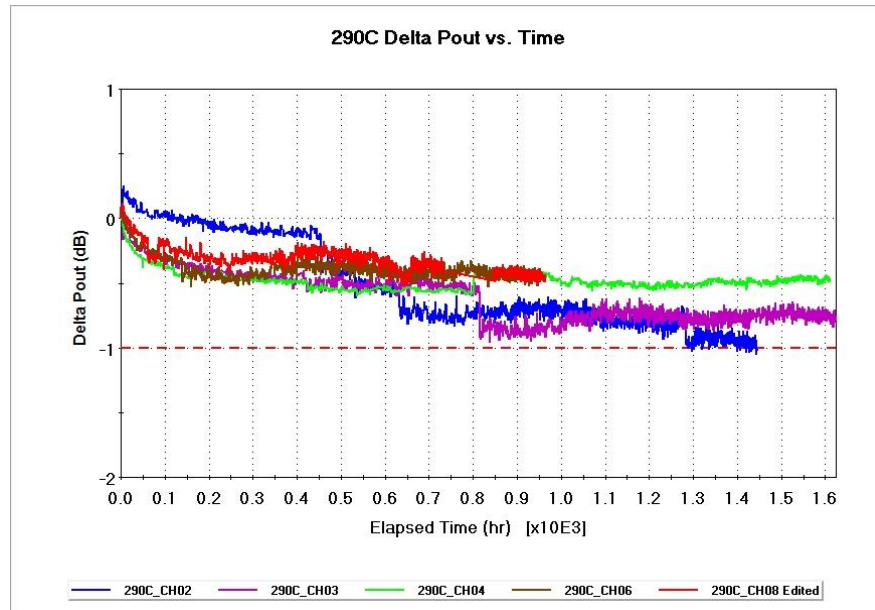


Figure 5 - RF Output Power vs Time for Channel Temperature of 290°C

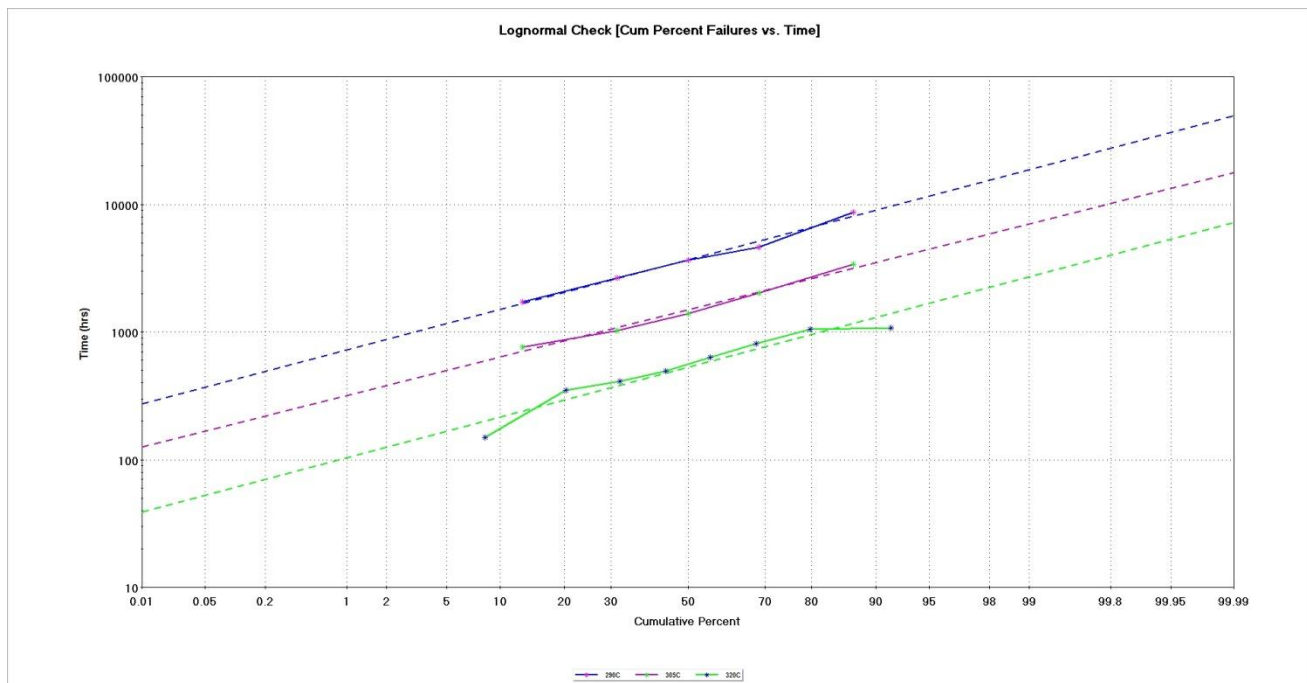


Figure 6 - Lognormal Cumulative Distribution of Failures

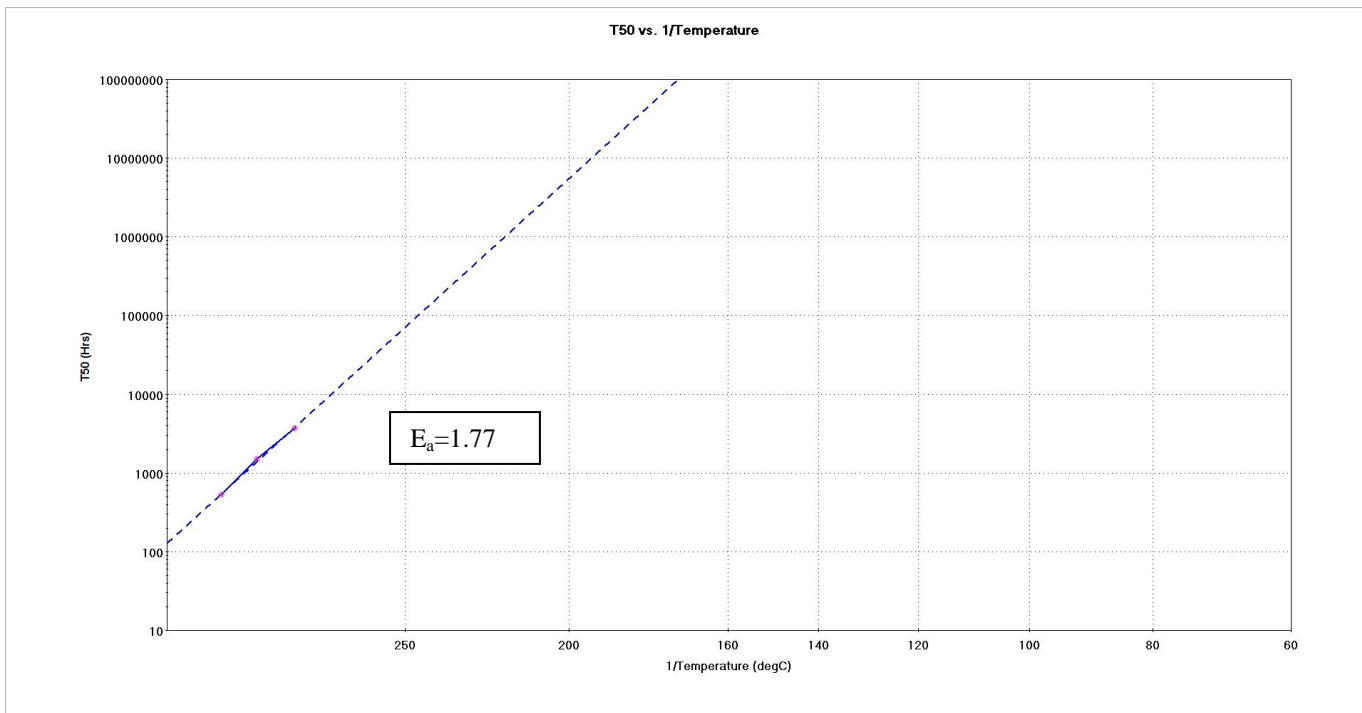


Figure 7 - Three-Temperature Arrhenius Plot to Extrapolate Lifetime