RF-Stressed Life Test of Pseudomorphic InGaAs Power HEMT MMIC at 44 GHz

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ABSTRACT

An RF-stressed accelerated life test was performed to establish the reliability of the recently developed high power HEMT MMICs at 44 GHz. The results showed a MTF (median time to failure) of 1.7×10^6 hours at 125°C channel temperature with the activation energy of 1.6 eV. The failure mode was a gradual output power degradation. A combination of surface states degradation and gate sinking were postulated as the failure mechanisms.

INTRODUCTION

To assess the reliability of the recently developed high power HEMT MMICs at 44 GHz, we performed a three-temperature RF-stressed accelerated life test. Our approach was to stress the MMICs at an electrical field level which is equivalent to that encountered during the nominal operation of the SSPA at the elevated device channel temperatures. The life test samples were assembled into waveguide fixtures which were similar to the modules used in the actual SSPA. The MMIC amplifiers were driven at 3 dB compression during the life test to reflect the worst case condition for the designed application. A degradation of 1 dB in output power when measured at the room temperature was used as the failure criterion. The constant stress life test was performed at 205, 215 and 225 °C channel temperatures. Throughout the life test, the DC and RF parameters of the amplifiers were monitored and their performance was evaluated at room temperature at selected time intervals. The failure mode for all the test samples was the RF output power degradation. This output power degradation correlated well with the degradation of the amplifier small signal gain. Based on the activation energy and the post-life test electrical parameter changes, a combination of surface oxidation and gate sinking processes were postulated as the failure mechanisms for these power HEMT MMICs. The projected mean time-to-failure of 1.7E6 hours at 125°C channel temperature demonstrates that the pseudomorphic InGaAs power HEMT MMIC can be reliable in meeting the applications such as the space-ground terminal communication.

TESTING PROCEDURES AND RESULTS

The device MBE structure, fabrication process, and circuit performance were reported earlier[1]. The life test system and procedures are described as follows:

RF life test system. We designed and built five RF life test racks that allow us to conduct a total of 20 MMICs RF life test concurrently. Figure 1 is the schematic diagram of a basic system that will accommodate up to four test samples in a well-controlled environment. We used free running IMPATT oscillators as the RF source since they are readily available in-house and have excellent power output. The IMPATT oscillator output power of 25 dBm was split two ways and attenuated through variable attenuator to 18 dBm before it was applied to the input of the test sample. The output from the test sample was first attenuated and then guided through a crystal power detector for output power monitoring. A pair of stainless steel waveguide sections was used to sandwich the test sample that was attached to a hot plate to minimize the heat transfer to other RF passive components.

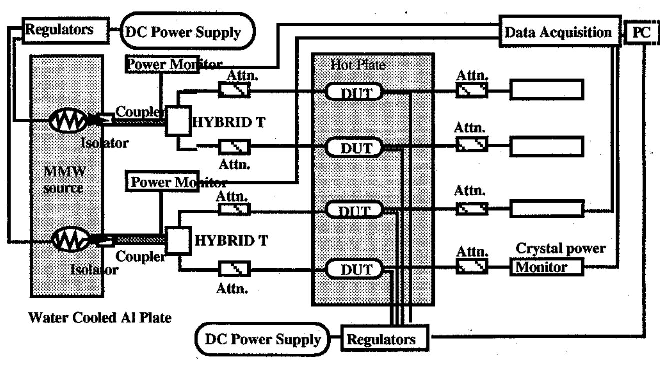

Figure 1. A schematic diagram of RF life test system.

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This RF life test rack has a computer-based monitor and data acquisition system that can simultaneously monitor all MMICs during life test. In particular, the drain current, gate voltage, and operating temperature of each DUT is continuously monitored.

Life test conditions:

- Normal DC bias and RF drive at 3 dB compression at elevated temperatures
- Monitor DC parameters and input/output powers in situ during life tests
- Evaluate RF parameters at room temperature for interval testing: output power, and linear gain
- Post burn-in ambient RF performance used as life test baseline data.

RF evaluation: The RF parameters were evaluated at pre/post burn-in and at each interval test during the constant stress accelerated life tests using the waveguide power measurement test equipment. The power HEMT channel temperature was estimated based on the DC power dissipation, the base plate temperature, and the device thermal impedance as determined by finite element thermal analysis and liquid crystal measurements. An output power change of 1.0 dB at 44 GHz is used as the failure criterion.

DC/RF Ids characterization: The MMIC was characterized at high temperature. As shown in Fig. 2, the drain current (Ids) without RF (Figure 2a), is considerably different from that with RF (Figure .2b). These RF Ids temperature coefficients were used during the life test to compensate the Ids at high temperature.

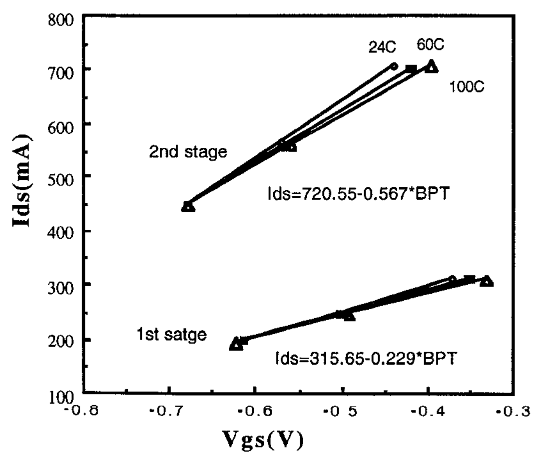

Figure 2(a). Drain current vs. gate voltage at different base plate temperatures (without RF).

Life test results: The RF degradation is illustrated in Figures 3(a), (b) and (c) for 205°, 215° and 225°C life tests. The failure time was determined by

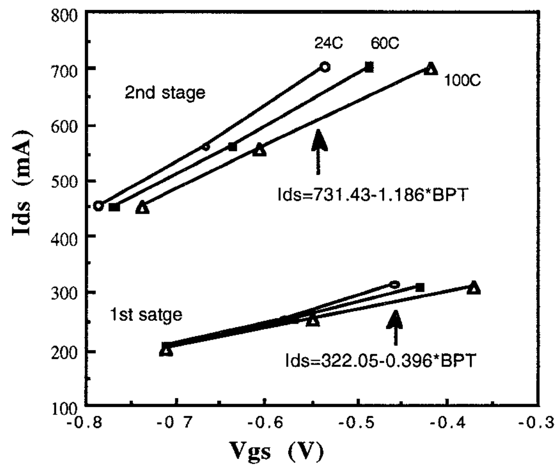

Figure 2(b). Drain current vs. gate voltage at different base plate temperatures (with RF).

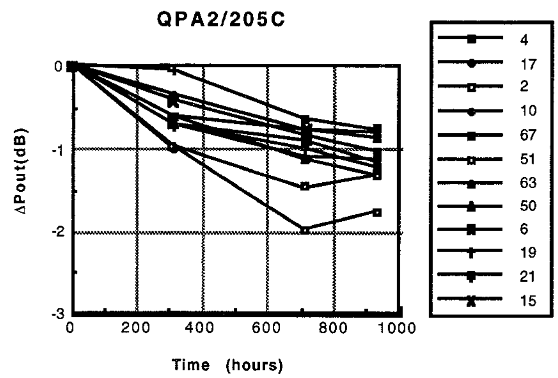

Figure 3(a). Output power vs. time, CS RFLT at 205°C channel temperature.

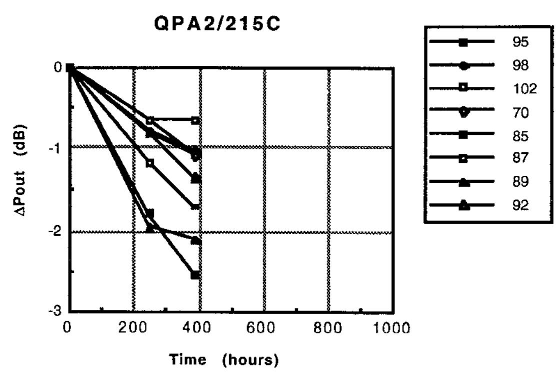

Figure 3(b). Output power vs. time, CS RFLT at 215°C channel temperature.

interpolation or extrapolation assuming the output power change is linear between test intervals. There are 12 units for 205°C, 8 units for 215°C, and 8 units for 225°C.

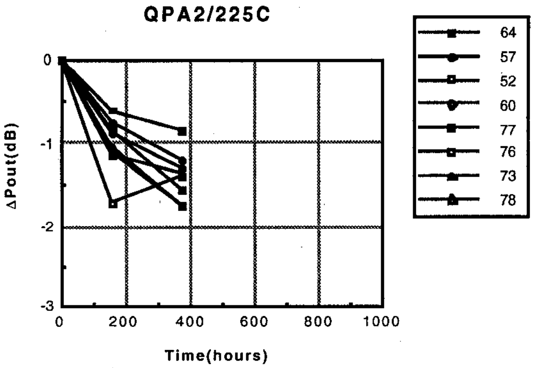

Figure 3(c). Output power vs. time, CS RFLT at 225°C channel temperature.

Data analysis: A log-normal distribution was commonly used to determine the MTF in microelectronic devices or circuits. We have followed this approach for estimating the MTF of the life tested HEMT MMICs. Figure 4 shows a log-normal distribution of the life tested Q-band MMIC based on output power degradation. The results followed a log-normal distribution with sigma value of 0.7. We used these plots to determine MTF at each temperature and plotted them in an Arrhenius relationship (Figure 5). An activation energy was determined to be 1.6 eV from this Arrhenius plot. The MTF at 125°C is projected to be 1.7 x 10^6 hours.

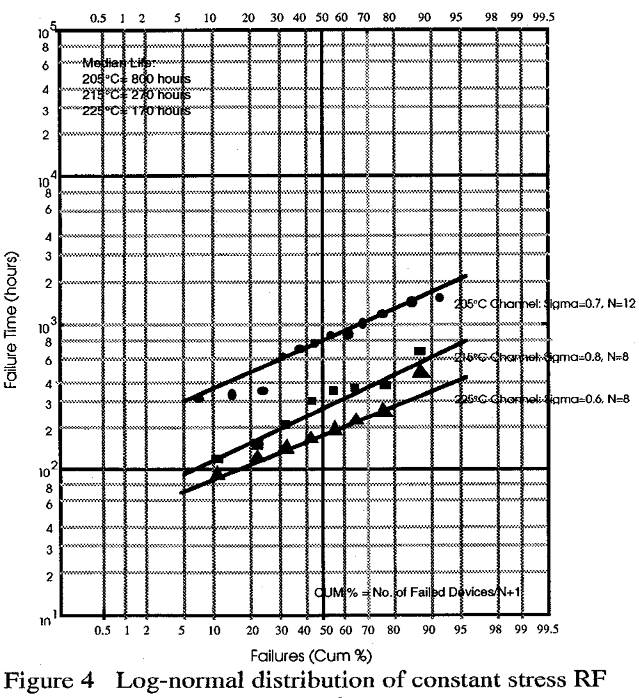

Figure 4 Log-normal distribution of constant stress RF life test of power HEMT MMICs.

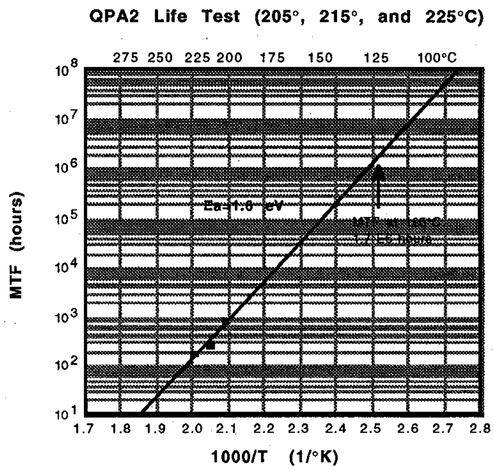

Figure 5 Arrhenius plot of 3-Temp constant stress RF life test, Q-Band power HEMT MMICs.

FAILURE ANALYSIS AND MECHANISMS

RF parameters The output power was degraded as a function of time as shown in Figures 3(a)-(c). The power degradation is plotted against linear gain degradation to obtain more insights into the degradation mechanisms (Figure 6). The diagonal line is to indicate the equal power and linear gain degradations. Most of the MMICs fall along the line indicating an equal amount of degradation for all input power levels.

DC parameters The Ids currents are plotted in Figures 7a) and 7(b) for MMIC's under 205°C life test condition. The trend of degradation for other two temperatures is similar The facts that the output power dropped and drain current showed no significant degradation indicate that the failure mechanism may have involved the surface states change [2].

Failure mechanisms Based on the analysis given above, from both DC and RF parameter change, it is likely that the failure mechanism of Q-band MMIC is due to a combination of the surface state change at the recessed gate area and gate sinking [2,3,4]. These change of surface states can vary the Imax [4], increase the gate lag and consequently degrade the output power.

CONCLUSION

We have successfully completed a three-temperature constant RF stress accelerated life test of power HEMT MMIC at 44GHz. The activation energy of 1.6 eV due to gradual degradation was obtained from this life test.

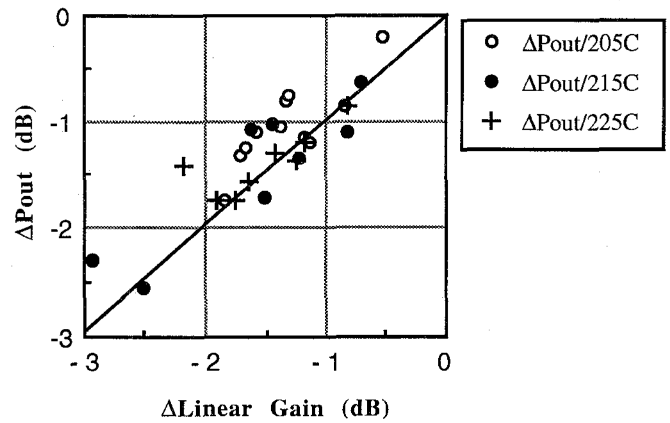

Figure 6. Correlation between Δpower and Δlinear gain.

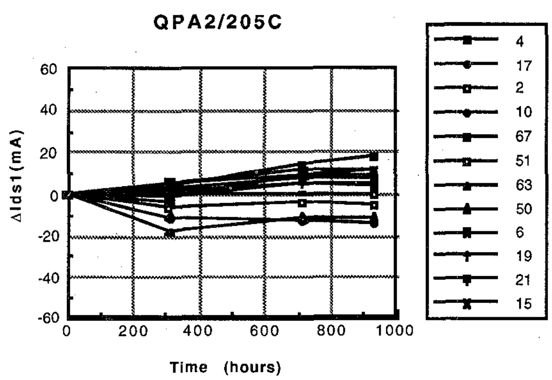

Figure 7(a). 1st stage drain current vs. time, CS RFLT at 205°C channel temperature.

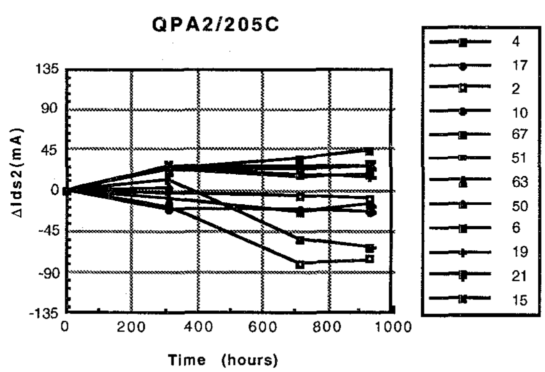

Figure 7(b). 2nd stage drain current vs. time, CS RFLT at 205°C channel temperature.

The projected mean time-to-failure of 1.7 x10^6 hours at 125 °C channel temperature indicates that this device technology can be reliable for critical applications at millimeter-wave frequencies.

ACKNOWLEDGMENTS

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