OPERATING CHARACTERISTICS OF 2-8 GHz GaAs MESFET AMPLIFIERS AT ELEVATED CASE TEMPERATURES TO 200 DEGREES CENTIGRADE

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Abstract

RF performance of 2-8 GHz amplifiers utilizing GaAs MESFETs which incorporate TiWN diffusion barriers is reported for a case temperature range of -54 to +200°C. Preliminary results of in-process accelerated life tests are also included.

Introduction

Military applications require reliable operation of microwave amplifiers at case temperatures to +100°C and higher. This challenging requirement would be greatly simplified by the availability of MESFETs capable of reliable operation at channel temperatures exceeding +200°C. Such devices would improve amplifier reliability and would allow significantly accelerated burn-in at 150 to 175°C case temperature, thereby reducing screening costs. Given the availability of improved devices, a number of questions about hybrid MIC amplifier construction techniques must also be reevaluated. Finally, the basic operational characteristics of amplifiers at such elevated case temperatures must be determined.

Device Description

The WJ-F105R GaAs MESFET was chosen as the test vehicle for a device improvement effort. This 300 x 0.5 micron deep-recess production device is commonly employed for power applications to 100 milliwatts from 1-20 GHz. Its reliability is primarily determined by degradation of the contact resistance to GaAs caused by interdiffussion of the ohmic contact and gold overlay. A diffusion barrier titanium-tungsten-nitride (TiWN) was developed and inserted between the ohmic and overlay materials.

A schematic cross-section of the new device is shown in Figure 1. The ohmic layer contains Ni, Ge, Au, and Pt. The 0.5 micron long Al gate is 3300 angstroms thick, capped with 200 angstroms of Ti. The Ti cap helps prevent Al hillock formation during subsequent processing and is intended to reduce electromigration. The next layer deposited is a diffusion barrier of 500 angstroms of dc reactively sputtered TiWN by a recently reported process[1]. The overlay metal is evaporated Ti-Pt-Au. The incorporation of the TiWN barrier has been demonstrated (Figure 2) to allow these devices to operate in a regime where devices without the barrier exhibit dramatic failures[2,3]. An added benefit of this TiWN barrier is that it also replaced a separate Ti-Pt-Ti-Pt layer previously inserted between the gate bonding pad and its overlay, thereby eliminating a masking/deposition operation.

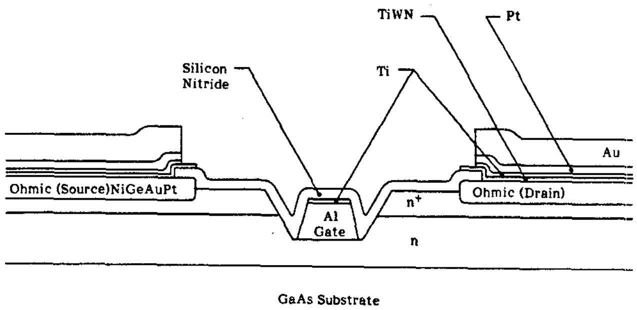
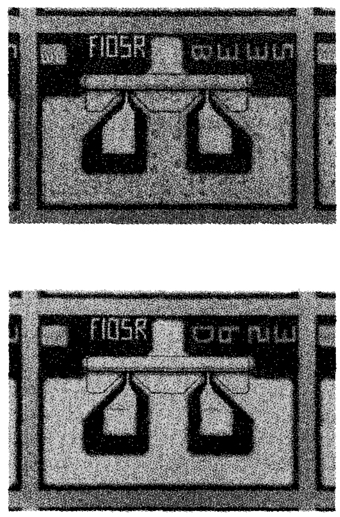


Figure 1. Cross-Section of the WJ-F105R GaAs MESFET with Titanium Tungsten Nitride Barrier Metalization (Not to Scale).



(a)

(b)

Figure 2. WJ-F105R GaAs MESFETs (a) with and (b) without Titanium Tungsten Nitride Barrier Metalization after a 24 Hour Bake at +300°C.

MESFET Circuit and Amplifier Construction

The availability of the new TiWN barrier WJ-F105Rs made possible fabrication of complete amplifiers for evaluation at elevated temperatures. It was decided to employ an existing 2-8 GHz circuit and established

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hybrid MIC production procedures and packaging, thus allowing evaluation of MIC procedures as well as the new devices. The two-stage amplifier is shown in Figure 3. It is enclosed in a Au plated kovar housing with fused glass to metal RF feedthrus, and is hermetically sealed with a seam welded Au plated kovar lid. Each amplifier consists of two cascaded balanced MESFET amplifier stages using conventional microstrip matching circuitry, as shown in Figure 4.

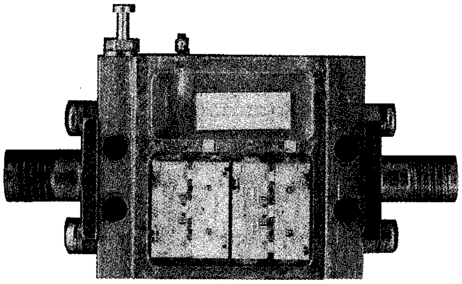

Figure 3. Two-Stage 2-8 GHz Balanced GaAs MESFET MIC Amplifier.

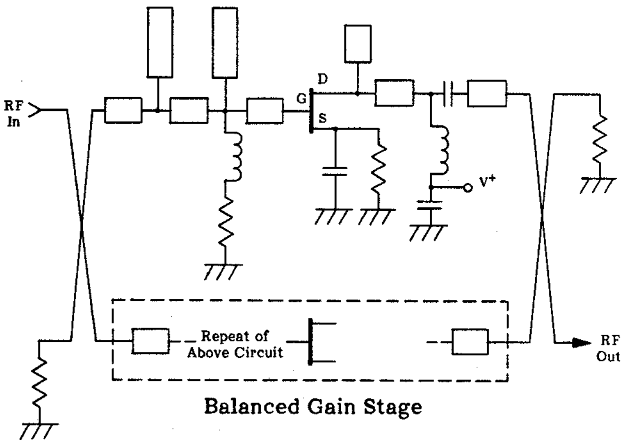

Figure 4. Amplifier Schematic and Block Diagram.

The amplifier cross-section is shown in Figure 5. The alumina substrates and Au plated copper rib are first brazed to a Au plated Mo carrier using Au-Ge eutectic material. The MESFET is then die attached to the rib using Au-Sn preform. Capacitors are also attached with Au-Sn. The completed MIC circuits are individually RF tested and then installed in the housing using silver filled epoxy cured at 180°C. This construction was designed to achieve substantial heat spreading in the high thermal conductivity Cu rib and Mo carrier so that the kovar housing bottom has minimal contribution to the total thermal resistance. Additionally, silver filled epoxy was chosen over mechanical fasteners because it completely fills any potential air gap between the carrier and housing floor. The amplifiers are baked at 150°C in a vacuum for 48 hours prior to sealing in a dry nitrogen environment.

Completed amplifiers were mounted on heaters with an aluminum spacer plate between the amplifier and heater. These spacer plates included a slot for insertion of a thermocouple probe to monitor the case temperature. The test apparatus for elevated tempera-

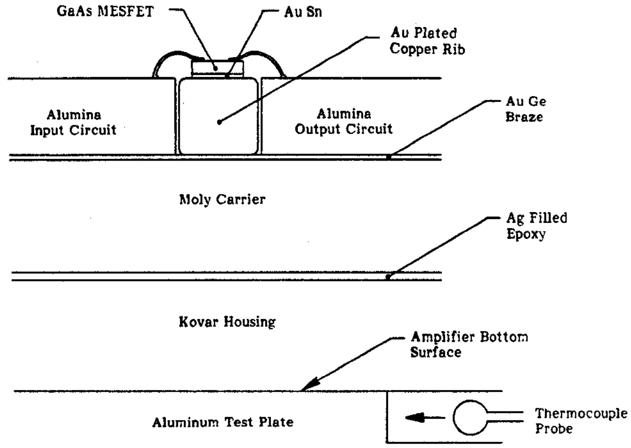

Figure 5. Amplifier Cross-Section and Mounting Configuration.

ture testing, shown in Figure 6, consists of three heater blocks, each capable of handling four amplifiers. Life testing is conducted under RF drive with the source signal power divided to each amplifier under test. Amplifiers were accessed individually for RF tests.

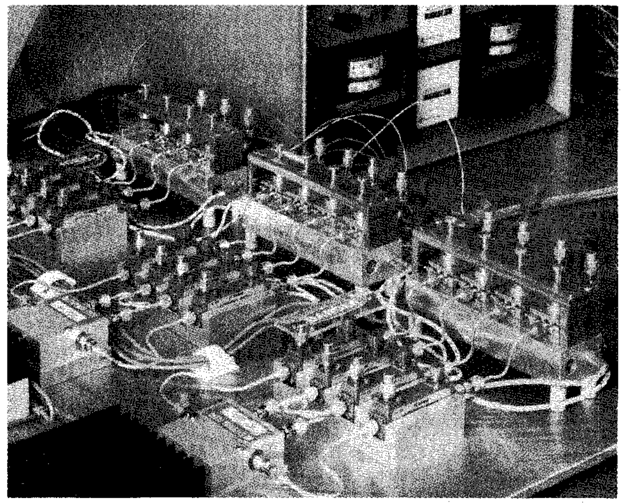

Figure 6. Apparatus for Amplifier Test at Elevated Temperatures.

RF Test Results

Eleven two stage 2-8 GHz amplifiers were tested for gain, input VSWR, output power at 1 and 3 dB gain compression, and noise figure at -54, -15, +25, +65, +100, +125, +150, +175, and +200°C. Typical gain as a function of frequency and case temperature is shown in Figure 7. Gain does not vary precipitously over this temperature range, and an overall flatness of ±1.0 dB is maintained over 2-8 GHz. Variation at 2 GHz differs from the midband variation due to the inappropriate choice of a capacitor in the output circuit, and could be improved by using a capacitor with reduced temperature sensitivity. Typical output power at 1 dB gain compression is shown in Figure 8. Output power exhibits little temperature dependence over -54 to +100°C, and degrades monotonically at higher temperatures. The GaAs MESFETs are biased at nominally 5 volts Vds and 55% Idss, for typical total amplifier dc current of 180 mA.

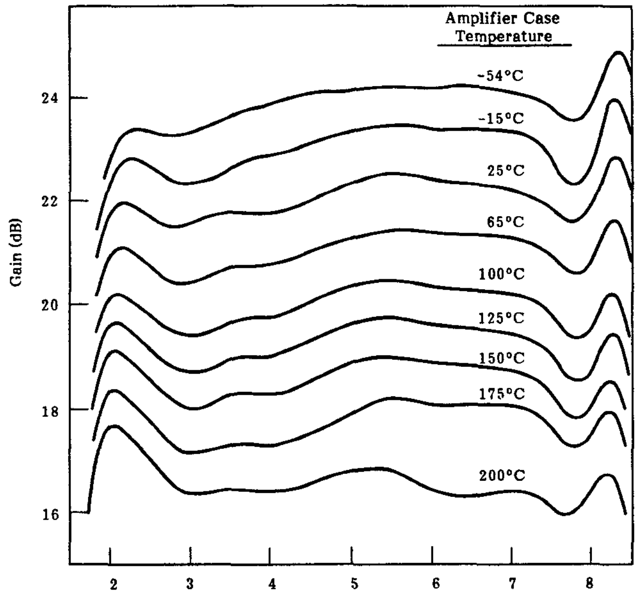

Figure 7. Measured Gain Versus Frequency at Various Case Temperatures for a Typical Amplifier.

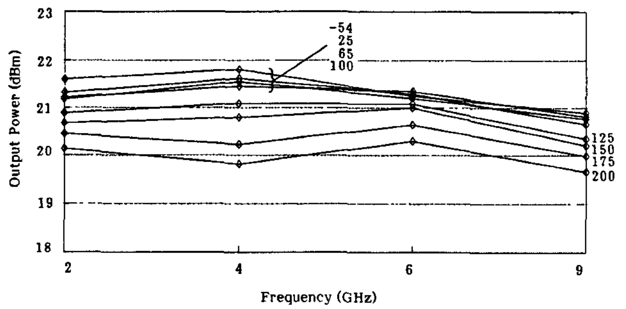

Figure 8. Measured Output Power ($P_{1\ dB}$) Versus Frequency for a Typical Amplifier.

Data was compiled to determine average operational characteristics. Midband gain at +25°C averaged 22.0 dB ± 0.44 dB standard deviation for 11 units. The average gain sensitivity to temperature is shown in Figure 9. The standard deviation in midband gain change (relative to +25°C) was under 0.15 dB to 150°C, rising to 0.35 dB at +175 and +200°C. Gain varied very linearly at -0.016 dB per degree C per stage for the temperature range of +65 to +200°C. Sensitivity is reduced to about -0.012 dB/degree at low temperatures. Average output power is shown in Figure 10 for +25 and +200°C. Output power frequency dependence is apparently due to the difference in output circuit match relative to the condition for optimum power match. This match condition exhibits some temperature dependence and is not maintained over the full 2-8 GHz bandwidth. DC current (Figure 11) exhibits significant temperature sensitivity due to the self bias dc circuit (Figure 4) which alters current as g_m varies. DC power decreases with temperature, but device thermal resistance increases with temperature. We estimate that the channel temperature exceeds the case temperature by about 40°C (-54°C case) to 50°C (+200°C case). Average noise figure as a function of frequency and case temperature is shown in Figure 12.

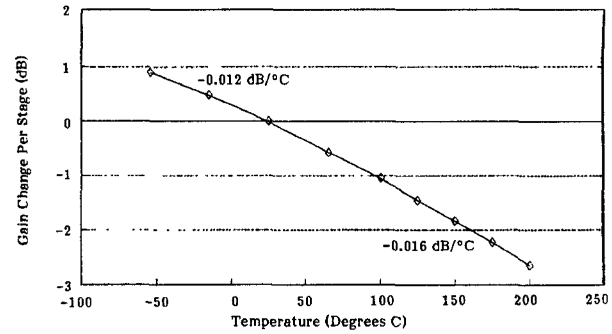

Figure 9. Average Change in Gain/Stage as a Function of Case Temperature.

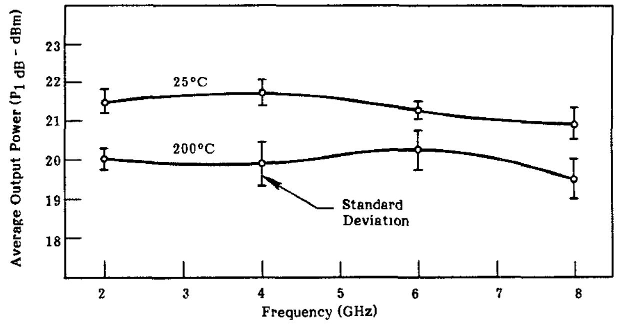

Figure 10. Average Output Power ($P_{1\ dB}$) Versus Frequency at +25 and +200°C.

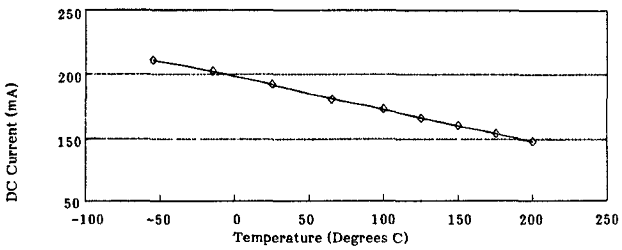

Figure 11. Average dc Current Dependence on Temperature (FETs are Shelf Biased, V_{Supply} = 6.0 Volts, 4 FETs/Amplifier).

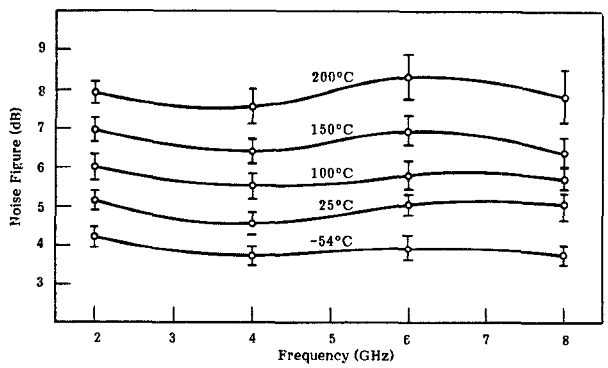

Figure 12. Average Noise Figure as a Function of Frequency and Temperature.

Preliminary Life Test Results

The eleven units were put on life test at the conclusion of the temperature testing. Four units were at +150°C, and seven units were at +175°C case temperature. These amplifiers exhibited minimal change in RF gain after 100 and 300 hours of operation. The test apparatus was then inadvertently altered such that the samples were subjected to very high continuous RF input levels (which induced high gate currents), and all samples failed catastrophically within 48 hours. Gate metal electromigration was determined to be the cause of failure, as would have been expected for the operating conditions[4]. An additional twelve single stage balanced amplifiers were then constructed and the life tests were repeated. These amplifiers were biased at +6.0 volts supply and driven with +3 dBm continuous RF input power. Four amplifiers were elevated to 150°C case temperature, and eight amplifiers were elevated to +175°C case temperature. The test was interrupted at various time intervals to 1015 hours and RF gain and dc current were measured at room ambient conditions. The average midband gain change is shown in Figure 13 (dc current changed by typically +0.9% at 1015 hours). Figure 14 presents swept gain at various time intervals for all twelve units, demonstrating minimal change in overall bandpass shape. The data of Figures 13 and 14 is for units with the original RF connectors. After completion of the 1015 hours gain measurements, the RF connectors were replaced and the measurements were repeated. Midband gain increased due to connector replacement by an average of +0.03 dB for the 150°C units, and +0.12 dB for the 175°C units. It is concluded that midband gain drop at 1015 hours, exclusive of connector effects, was and average of 0.1 dB for the units operated at +175°C case temperature (0.0 dB for 150°C units). Measurement repeatability is also about 0.1 dB. The same apparatus was used for all swept gain tests. Frequency dependent changes of up to 0.4 dB were determined to be completely dominated by connector aging.

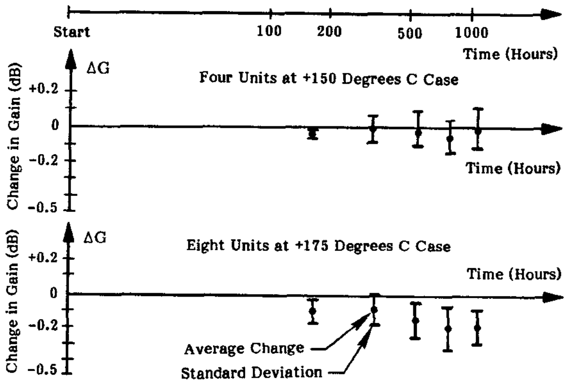

Figure 13. Change in Gain after Operation at Elevated Case Temperatures for Various Durations (Single-Stage Balanced Amplifiers, Operation with dc and +5 dBm RF Input Level, Gain Measured at Room Ambient Temperature).

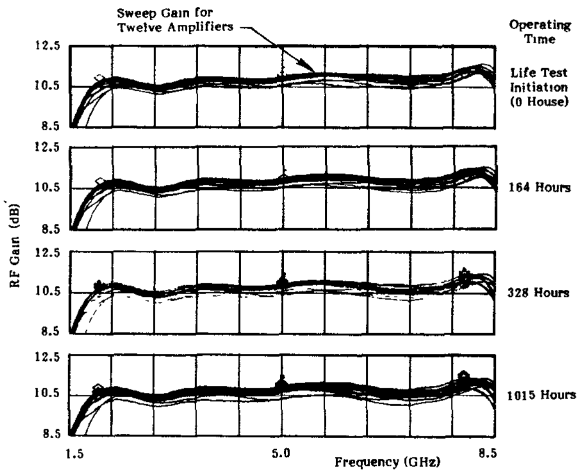

Figure 14. Swept Gain for Twelve Single-Stage Amplifiers at Different Time Intervals (4 Units at +150°C, 8 Units at +175°C Case Temperature, Gain Measured at Room Ambient).

Planned Future Work

The operating results obtained thus far are sufficiently encouraging that 2.7 mm power (approximately 1 watt) devices have recently been fabricated with the new process. We plan to construct 2-6 GHz one watt balanced MIC amplifiers with these devices, and to report RF results to +200°C at the 1987 MTT-S Symposium. In addition, this TiWN barrier process is now being applied to production WJ-F105R GaAs MESFETs.

Conclusions

GaAs MESFET devices with TiWN barrier metalization were incorporated in two stage 2-8 GHz MIC amplifiers. These amplifiers were evaluated over the case temperature range of -54 to +200°C - the highest operating temperatures yet reported for GaAs MESFET multistage MIC amplifiers. Preliminary life test results show the potential for reliable sustained operation at case temperatures to +150°C. The TiWN barrier MESFETs and the MIC amplifier construction techniques reported are expected to result in improved reliability for medium power GaAs MESFET amplifiers.

Acknowledgments

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References

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