HIGH RELIABILITY NON-HERMETIC 0.15 μm GaAs PSEUDOMORPHIC HEMT MMIC AMPLIFIERS

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ABSTRACT

High reliability performance of a Ka-band low-noise MMIC amplifier fabricated using 0.15 μm production AlGaAs/InGaAs/GaAs HEMT process technology is reported. Operating at an accelerated DC bias condition of Vds=5.2V and Ids=250mA/mm, two-stage balanced amplifiers were lifetested at three-temperatures ($T_{ambient}$=235°C, $T_{ambient}$=250°C, and $T_{ambient}$=265°C) in air ambient. Failure time for each temperature was determined using ΔS21=–1.0 dB measured at room temperature as the failure criteria. The activation energy (Ea) is 1.6 eV, achieving a projected median-time-to-failure (MTF) of $7x10^9$ hours at a 125°C junction temperature. This is the first report of 0.15 μm HEMT reliability based on S21 failure criteria of MMIC amplifiers under DC stress at high junction temperature in air ambient. This result demonstrates a robust HEMT technology immune to the stress effects of high electric field under high temperature operation suitable for non-hermetic commercial Ka-band applications.

INTRODUCTION

Recently, GaAs pseudomorphic HEMT MMIC amplifiers with excellent millimeter wave performance have been demonstrated to meet the needs of next generation commercial and military electronic systems [1-5]. A highly reliable GaAs pseudomorphic HEMT technology is necessary for both the space/defense and commercial markets. For space/defense applications, GaAs HEMT MMICs operate in a hermetic environment. However, to reduce the cost in commercial applications, operation of GaAs HEMT MMICs in a non-hermetic environment is desirable. Therefore, we have performed reliability evaluations of MMIC amplifiers in an air environment with excellent results. Previous published data has been on lower complexity discrete devices in nitrogen ambient [6-9].

PROCESS TECHNOLOGY

TRW's standard 3" GaAs pseudomorphic HEMT production process utilizes semi-insulating substrates grown by solid source molecular beam epitaxy (MBE). The channel carriers are supplied by two silicon delta doping layers (4.7×10^{12} cm^{-2} and 1.0×10^{12} cm^{-2}). The epitaxial layers have a 2-dimensional electron gas (2-DEG) carrier density of 3.56×10^{12} cm^{-2} and a Hall mobility of 4,600 cm^2/V-s at room temperature. While $Al_{0.25}Ga_{0.75}As$ with a thickness of 500Å is used as the Schottky barrier layer, $In_{0.22}Ga_{0.78}As$ with a thickness of 140 Å is used as the channel layer. A heavily-doped GaAs layer is used to facilitate the ohmic contact formation.

Ni/AuGe/Ag/Au and refractory Ti/Pt/Au are used for the drain & source ohmic metal and gate contact, respectively. A 0.15 μm T-gate shown in Figure 1 was patterned by a two-layer resist PMMA, P(MMA-MAA) electron beam lithography system. The gate recess profile was controlled by a wet-etch process. After the gate definition, the device was fully passivated by 750 Å Si_3N_4.

Other key process features include 100 ohms/sq NiCr thin film resistors (TFR), 130 ohms/sq bulk resistors, 320 pF/mm^2 metal-insulator-metal (MIM) capacitors, spiral inductors, air-bridge cross-overs, backside ground vias and SiN passivation. All processed wafers are subjected to in-line screening that includes process control monitor (PCM) testing of passive and active elements, unbiased stabilization

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bake at 240^{o}C for 48 hours, DC electrical and RF test, and visual inspection.

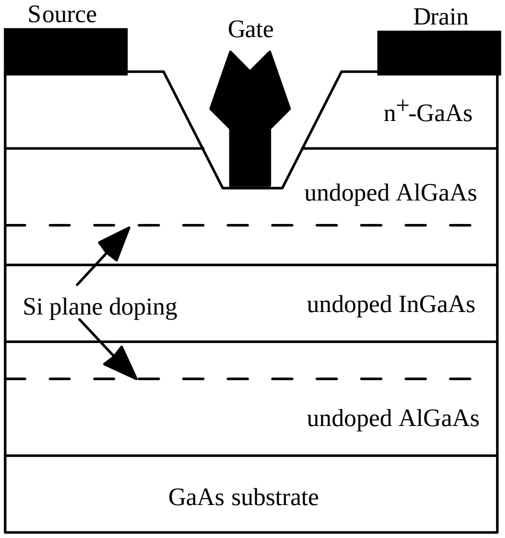

Fig.1: Cross section of a GaAs pseudomorphic HEMT.

STANDARD EVALUATION CIRCUIT

The 35BLNA MMIC was the standard evaluation circuit used to evaluate the non-hermetic reliability of the GaAs pseudomorphic HEMT process. The 35BLNA is a two-staged balanced amplifier operating in the frequency range of 30 – 40 GHz with a typical gain of 12 dB. It contains four PHEMTs with a total gate width of 400 µm. During lifetest, the 35BLNA PHEMTs were biased at Vd=5.0 V and Ids= 250 mA/mm and bulk drain resistors at 0.5 mA/µm. A micrograph of a 35BLNA MMIC is shown in Figure 2.

NON-HERMETIC RELIABILITY TESTING

Reliability evaluation of GaAs pseudomorphic HEMTs at TRW was determined by a three-temperature constant stress lifetest. Aging of discrete passive and active components is accelerated by the elevated temperatures under full DC bias. An Arrenhius model is used to predict the mean time to failure at the temperature of interest by extrapolation.

A total of 90 MMICs were randomly selected across 5 wafers from 2 standard TRW 3” production process lots. All the selected MMICs passed on-wafer DC, RF (S-parameter and noise figure) and visual screening requirements. All parts were assembled and burned in at 150 ^{o}C for 48 hours in air ambient. The parts were biased at Vds=4.2V, Ids=150mA/mm during burn in.

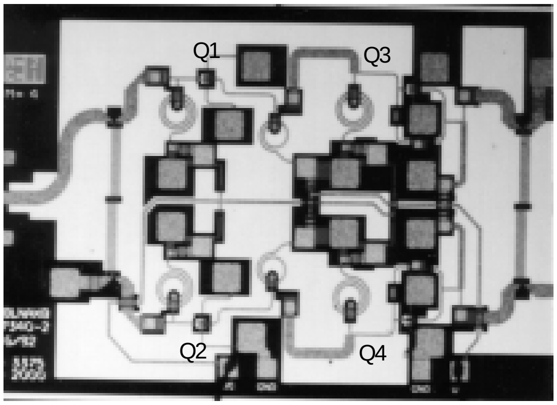

Fig.2: Micrograph of a Ka band balanced amplifier operating over 30-40 GHz. Chip size is 2 mm x 3.375 mm.

The 35BLNA MMICs were stressed under DC bias @ Vds=5.2V, Ids=250mA/mm in air ambient for the step stress and each of the three lifetests. RF and DC tests were done at room temperature. S-parameters were measured with Vds=4.2V, Ids=150mA/mm from 30 to 40 GHz. The DC measurements included Gm, Ids, Ig, ideality factor and Schottky barrier height.

A step stress was first done to determine suitable temperatures for lifetesting. Ten 35BLNA MMICs were stressed at successively higher ambient temperatures in air ambient. The temperatures ranged from 150^{o}C to 300^{o}C and the stress duration was 48 hours for each temperature. Figure 3 shows the gain change in a typical MMIC after each step. The S21 change over the 30-40 GHz interval is small for each of the test intervals where $T_{ambient}<275^{o}$C. However, S21 degraded approximately 2.5-3 dB after completion of the final 300^{o}C step. The S21 change at $T_{ambient}=300^{o}$C was correlated with the decrease of Schottky barrier height indicative of gate sinking. The change in Schottky barrier height is illustrated in figure 4. In region I, ($T_{ambient}<=275^{o}$C), the Schottky barrier height shows no change. However, in region II ($T_{ambient}=300^{o}$C), Schottky barrier height decreases from 0.75 eV to 0.55-0.66 eV, accompanied by Gmp degradation. This indicates that gate sinking induces the degradation of microwave performance at $T_{ambient}$=300°C.

Based upon the step stress results, lifetest temperatures were chosen to be $T_{ambient}$ =235°C, 250°C, and 265°C for the three-temperature lifetest. The estimated junction temperature rise above ambient is approximately 90°C for the biasing conditions Vds=5.2V, Ids=250 mA/mm. This gives a remarkably high junction temperature of 355°C for the highest temperature. The failure criterion was a 1.0 dB degradation of S21 at 35 GHz.

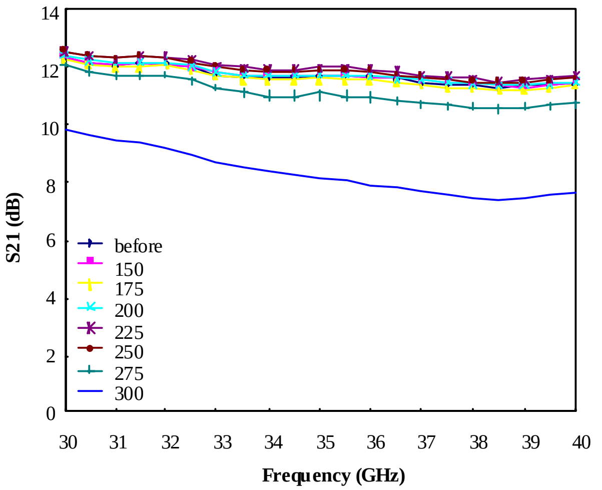

Fig.3: Room temperature S21 characteristics of a Ka-band MMIC amplifiers subjected to step stress from 150°C to 300°C. S21 degradation was observed only at $T_{ambient}$=300°C.

RESULTS

The lifetest failures for each temperature exhibited a log-normal distribution with a temperature-independent log-standard deviation (sigma). The lifetest failure distribution is plotted on a log-normal scale shown in Fig.5. Measured sigma was approximately 0.3.

Figure 6 is an Arrhenius life-temperature plot based on the median failure time measured at each lifetest temperature. The junction temperature rise has been factored into Figure 6. The Arrhenius model projects a MTF of 7×10^9 hours at a junction temperature of 125°C with an activation energy (Ea) of 1.6 eV.

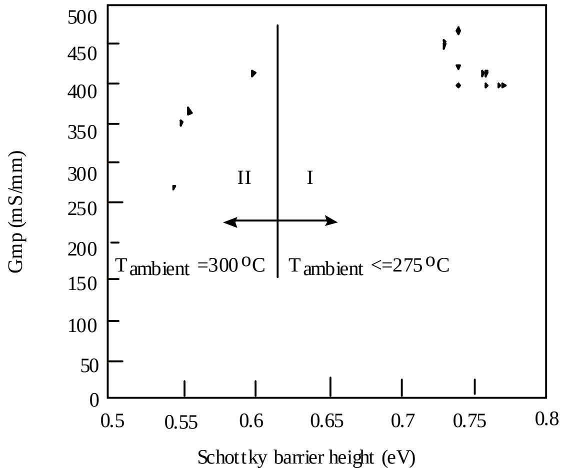

Fig.4: Correlation of Schottky barrier height and peak Gm. The S21 change at $T_{ambient}$=300°C was correlated with the decrease of Schottky barrier height indicative of gate sinking.

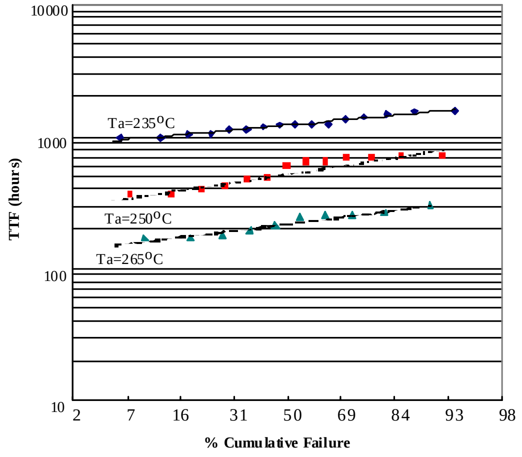

Fig.5: Lifetest failure distribution plotted on a log-normal scale. Ta is the ambient temperature.

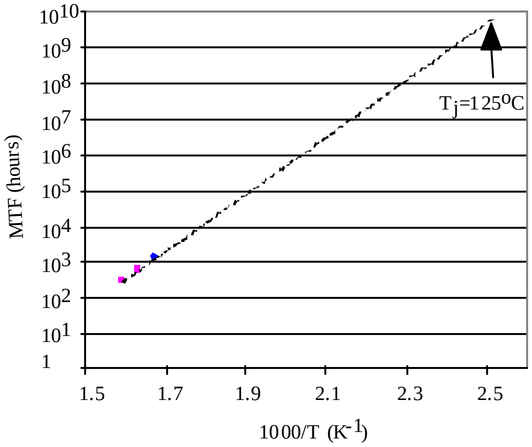

Fig.6: Arrhenius plot for HEMT MMIC amplifiers stressed at Vds=5.2 V, Ids=250 mA/mm under Tj=325°C, 340°C, and 355°C. The projected median-time-to-failure (MTF) is 7×10^9 hours at Tj=125°C.

CONCLUSION

A Ka-band 0.15 μm GaAs pseudomorphic HEMT MMIC fabricated using TRW's 3" production process was demonstrated to have excellent reliability. A three-temperature lifetest in an air ambient resulted in an activation energy (Ea) of 1.6 eV, with a projected median-time-to-failure (MTF) of $7x10^9$ hours at a junction temperature of 125^oC. This is the first reliability report of 0.15 μm HEMT MMIC amplifiers under DC stress at high junction temperature. This result demonstrates a robust HEMT technology immune to the high electric field stress effects in air ambient crucial for non-hermetic commercial Ka-band applications.

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