AlGaAs/GaAs HBT Reliability: Dependence on Material and Correlation to Baseband Noise[#]

Burhan Bayraktaroglu*, Gilbert Dix*, Saeed Mohammadi¶, and Dimitris Pavlidis¶
*Northrop Grumman Corporation,
P.O. Box 1521, MS 3K13, Baltimore, MD 21203
¶The University of Michigan,
Dept. of Elect. Eng. and Comp. Sci., Ann Arbor, MI 48109

Abstract - The long-term reliability of AlGaAs/GaAs HBT was found to have a strong dependence on the starting epitaxial material. The measured and extrapolated lifetimes ranged from 10^2 to 10^9 hours with devices fabricated on wafers obtained from 3 different vendors. The low frequency baseband noise characteristics were used to identify the source and the nature of mechanisms that lead to current gain degradation.

I. INTRODUCTION

The reliability of GaAs-based HBTs has shown a steady improvement over the last decade. The short term failure mechanisms related to thermal runaway are now well understood and solutions have been implemented.[1,2 The long term failure mechanisms manifested by current gain degradation is still being investigated. Recently, the projected lifetime values for HBTs operating at moderate current densities (20-40 kA/cm^2) has shown a remarkable improvement when the epitaxial layer properties were modified. Some of the examples of these modifications are indium co-doping of the base[3], and the use of InGaP as the emitter, which resulted in MTTF values of over 10^7 hours [4].

We have undertaken an investigation to correlate the epitaxial layer properties to long term reliability by fabricating the same devices on wafers obtained from 3 different commercial vendors. Apart from tracking the current gain change as the devices are stressed with constant current DC bias at elevated temperatures, we have measured the baseband noise characteristics of devices before and after degradation to establish a correlation between some components of the noise characteristics and the long term reliability of the device. The noise measurements were also used to identify the source and the nature of mechanisms that lead to degradation under bias stress.

II. DESIGN AND FABRICATION

All devices used in this investigation were fabricated on wafers grown by metal organic chemical vapor deposition (MOCVD) technique. Wafers were obtained from 3 different commercial vendors. The same epitaxial layer design was maintained for all the wafers although some variations in layer properties or interfaces between layers may have existed due to each vendor's epitaxial growth method. The base layer was doped with carbon at 4E19 cm^{-3} concentration. Its thickness was kept constant at 100 nm. The measured base sheet resistivity was in the 220-240 ohm/sq. range. A thin layer of InGaAs layer was used for non-alloyed emitter contacts. A self-aligned emitter-base fabrication process was used to consistently fabricate base contacts 0.4 μm away from the emitter mesa edge. The extrinsic base surface was passivated with a silicon nitride layer. No intentional "ledge" structures were employed although such approaches have shown to have an influence on the baseband noise characteristics of HBTs.[5, 6]

All devices examined in this study had the same emitter area (160 μm^2). The cell designs were consistent with power amplifier applications. Thermal shunt[7] structures were used between emitter fingers to avoid thermal instabilities. Several emitter finger designs were used to obtain cells with varying emitter periphery/area ratios. To ensure that wafer processing did not introduce variations, wafers from all vendors were processed simultaneously in the same lot.

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All devices were mounted in special packages for stress and electrical tests. First, the dc and noise characteristics were measured. The same measurements were repeated after each device completed stress tests. The noise measurements included both the base and the collector current noise spectra as a function of bias current. Similar measurements were performed as a function of junction temperature to identify the trap levels. The accelerated stress tests were performed with constant collector current at elevated junction temperatures.

III. RESULTS AND DISCUSSION

A. Lifetime Tests

Figure 1 compares the current gain variation as a function of time at 125°C junction temperature on the same device type fabricated with low- and high-reliability wafers. Each device was biased at 3 V, and 25 kA/cm^2 emitter current density. Under these conditions, the low reliability devices show degradation within a few hours, while the high reliability device performance remains unchanged for thousands of hours. The performance of devices fabricated on medium reliability wafers was about an order of magnitude better than the low reliability devices.

The effect of the device design on reliability is shown in Figure 2 for devices fabricated on medium reliability wafers. While the emitter area was kept constant at 160 μm^2 in these devices, the periphery was varied by changing the emitter finger width and length. Although the degradation rates are different from one another, Figure 2 shows that there is no particular lifetime dependence on the periphery/area ratio. This is consistent with the noise measurements, which indicated that the base and collector current noise characteristics were almost identical for devices from the same wafer but with different periphery/area ratios.

Accelerated lifetime tests were carried out to determine the projected lifetimes. Because the failure rates were rapid with devices fabricated on low and medium reliability wafers, only the high reliability devices were subjected to these tests. Using 30% degradation in current gain as the failure criteria on devices stressed at elevated temperatures, a t_{50} lifetime of 10^9 hours was extrapolated at a junction temperature of 120°C. The activation energy was 1.5 eV. These results are shown in Figure 3.

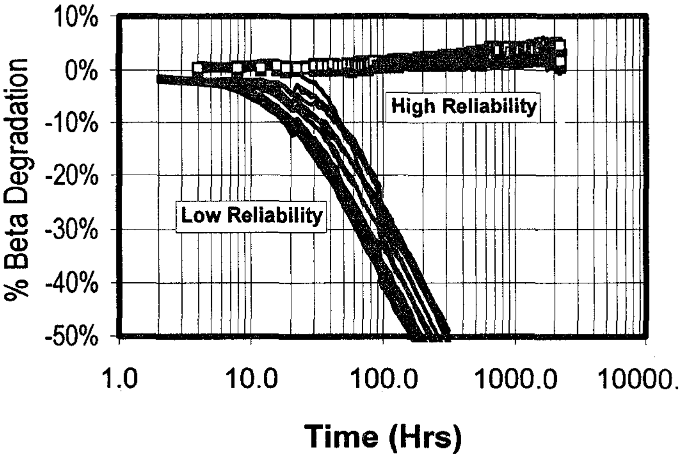

Figure 1: Long term reliability of devices fabricated on wafers from different commercial vendors.

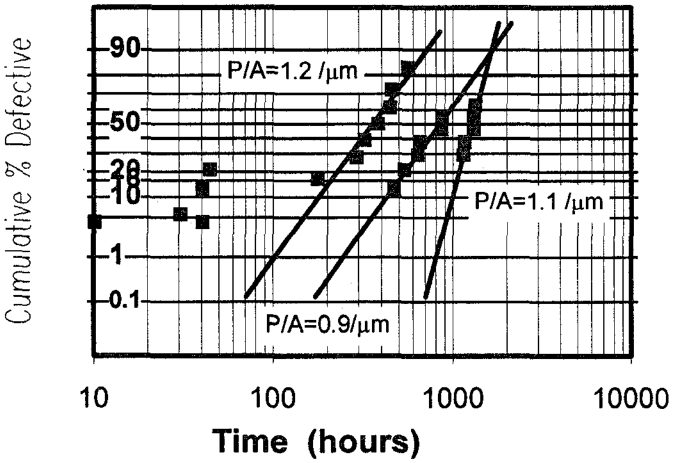

Figure 2: Measured lifetimes for devices with varying periphery-to-area ratios..

B. Baseband Noise Measurements

Bias dependent low frequency noise characteristics were measured on devices before and after stress testing to determine a correlation between noise and the long-term reliability. Low temperature noise characterization was used to find the generation-recombination component of the noise and therefore determine the trap centers within different regions of the device.

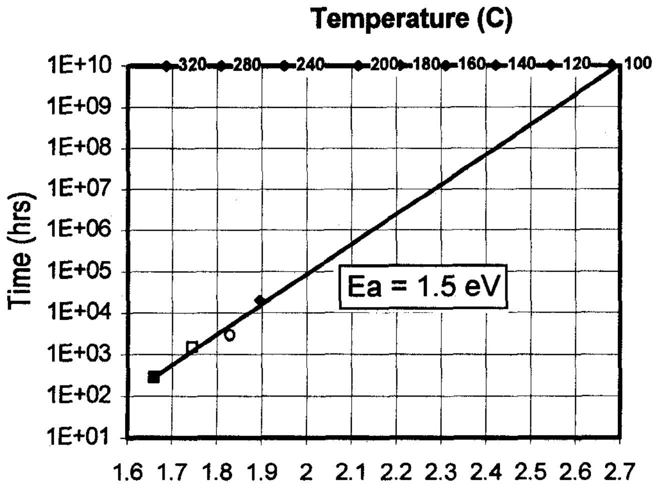

Figure 3: Arrhenius plot of MTTF vs. 1/T for devices biased at 25 kA/cm^2 current density.

Figure 4 shows the base noise spectral density of low and high reliability HBTs for different base currents (I_b= 0.05 mA and 0.25 mA). As seen in this figure, the high reliability HBTs show a much smaller noise level and a weak dependence on bias compared to low reliability devices. After stress biasing at elevated temperatures to cause 20% degradation in current gain, both types of devices showed an increase in the base noise. The increase was more pronounced at higher bias currents for all devices.

Figure 5 shows the collector noise spectral density of low and high reliability HBTs. At lower frequencies, the collector noise increases as the devices become less reliable. At higher frequencies, however, the higher reliability HBT shows comparable or even higher noise than the lower reliability devices. After the devices were subjected to stress bias, the collector noise magnitude at higher frequencies did not change, whereas the 1/f component showed an increase. There was a widespread variation in the bias dependent behavior of the collector noise on devices fabricated on the same wafer. Overall, there appears to be no significant correlation between HBT collector noise and its long term reliability.

Low temperature noise measurements were employed to reveal the characteristics of generation-recombination (g-r) centers located close to base-emitter and base-collector junctions. It was found that activation energy levels did not change after the low reliability devices were stressed. However, the density of g-r centers corresponding to the base current noise showed an increase, as shown in Figure 6. The density of g-r centers corresponding to the collector noise showed only a very slight increase. The activation energy levels of traps for both the base and the collector noise of the low reliability HBTs were in the 120 to 150 meV range.

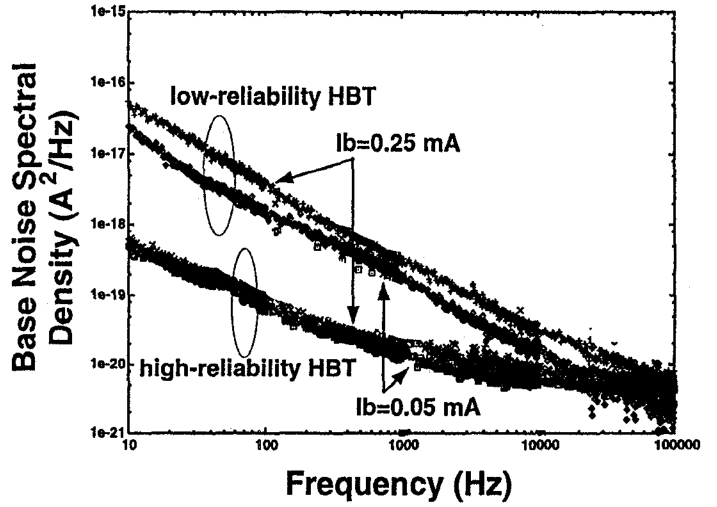

Figure 4: Comparison of low frequency base current noise of high- and low-reliability HBTs.

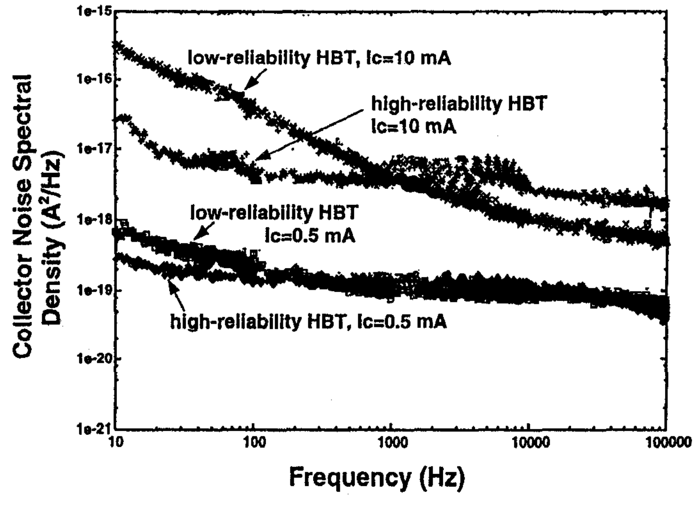

Figure 5: Comparison of low frequency collector current noise of high- and low-reliability HBTs.

IV. CONCLUSIONS

Based on the dc electrical measurements and the noise characterization on devices before and after stress tests, it is concluded that HBT current gain degradation does not create new trap levels; only the population of traps is increased. The reliability of HBT seems to be dependent on the initial population of traps, which may be varied with epitaxial layer preparation. Finally, it was demonstrated that the devices fabricated on wafers with smaller trap densities (lower 1/f noise) can have extremely high reliability.

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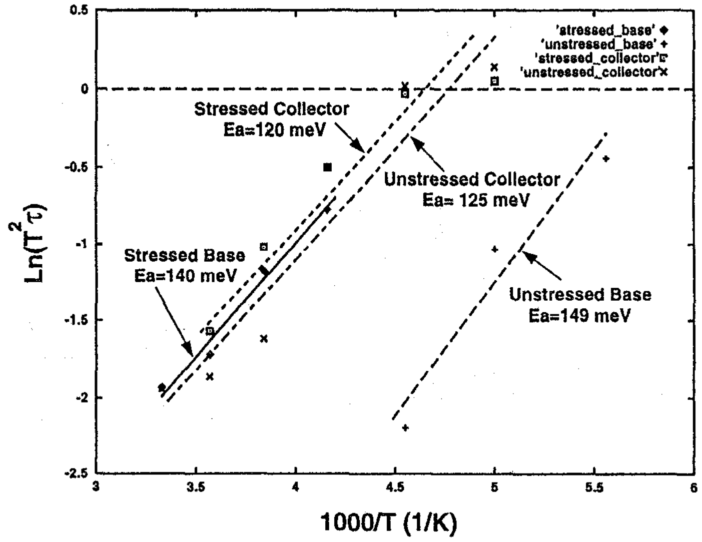

Figure 6: Arrhenius plot for evaluating trap activation energy before and after stress tests.

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