Low-Frequency Noise Characterization of High- and Low-Reliability AlGaAs/GaAs Single HBTs

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Abstract: Self-aligned AlGaAs/GaAs Single HBTs were fabricated using different epilayers with identical layer structure and processing technology. These HBTs manifested different long-term reliability characteristics despite their identical device design and similar DC characteristics. The low-frequency noise characterization of these devices revealed generation-recombination centers with activation energies from 120 meV to 200 meV. The base-emitter region 1/f noise of these devices was found to be in correlation with the long-term reliability.

I. Introduction

AlGaAs/GaAs heterojunction bipolar transistors (HBTs) are being explored for a large number of microwave power applications [1][2]. Their reliability has been studied using bias and thermal stressing techniques [3][4]. The technique explored in this work is based on a possible relationship between low-frequency noise properties and HBT reliability[5]. Recently the long-term reliability of HBTs has been improved to values comparable to Silicon devices. Using different methods such as Indium co-doping in the base as well as GaInP emitter, has resulted in MTTF values over 10^7 hours[6].

II. Device Technology and Electrical Characteristics

Single heterojunction self-aligned AlGaAs/GaAs HBTs were fabricated on Metalorganic Chemical Vapor Deposition (MOCVD) grown layers. The same device design was used for all devices analyzed in this work, but MOCVD materials of different origin were employed for comparison. Identical technology was used for HBT processing to minimize the influence of technology on reliability characteristics. The DC analysis of 8 finger 2.5 µm x 20 µm HBTs revealed a current gain (β) of 30 and very similar Gummel, β vs. I_c and I_c-V_{ce} characteristics independent of layer used. The microwave analysis of HBT characteristics revealed f_T and f_{max} values of 60 and 100 GHz, respectively.

The HBTs were subjected to bias and temperature stress to evaluate their long-term reliability. The stress test was performed under 25 kA/cm^2 and 125 °C junction temperature using 20% degradation in current gain as criterion for reliability. A median time to failure (MTTF) of 100 hours (low-reliability devices) to 10^9 hours (high-reliability devices) was evaluated. The degree of device reliability appeared to depend on the choice of material used for fabrication.

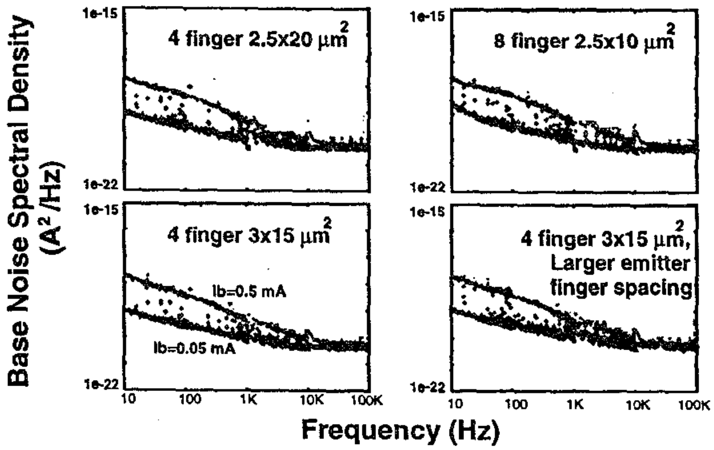

Fig. 1: Base noise of HBTs with different emitter geometry. Results permit investigation of P/A influence on noise.

III. Low-Frequency Noise Characterization

Low-frequency noise tests were performed using an HP3561A dynamic signal analyzer and a system with specially made bias networks to minimize the influence of external components on noise measurement [7]. Tests of low and high-reliability HBTs were performed on 38 devices under different bias conditions. The devices were also measured under variable temperature conditions in order to study the presence of generation-recombination noise and traps associated with it.

The origin of 1/f noise was first investigated by studying several devices with the same emitter area but different perimeter to area ratio (*P/A*). No geometry-dependence was observed for the base low-frequency noise as shown by Fig. 1. The same observation was also made for collector noise. Therefore, it was concluded that the origin of the low-frequency noise of these HBTs is not related to surface effects. These observations are in agreement with long-term reliability tests, which show no particular dependence on *P/A*.

Fig. 2 shows the collector noise spectral density of stressed and unstressed low and high-reliability HBTs. The collector voltage V_{ce} was 3 *Volts* and the collector current, I_c was set to 0.5 *mA* and 10 *mA*. The base was grounded with a large capacitor to eliminate the base noise current. The collector noise observed in these devices has a 1/f noise component with a relatively low corner frequency (f_{corner}) ($1\ kHz < f_{corner} < 10\ kHz$ for low-reliability HBTs and $200\ Hz < f_{corner} < 1\ kHz$ for high-reliability HBTs). The results of Fig. 2 show that the magnitude of the 1/f noise component increases upon stress for both low and high-reliability HBTs. However, stress does not affect the HBT collector noise at higher frequencies. These trends suggest that the 1/f noise component of collector noise spectral density can be indicative of the device quality. Statistically, however, it was found that the collector noise spectral density of low and high-reliability HBTs is comparable and cannot consequently be used as a good measure of device quality and reliability.

Fig. 3 shows the base noise spectral density of the low and high reliability HBTs measured before and after stress. The bias condition was $V_{ce} = 3$ *Volts* and $I_b = 50\ \mu A$ and $250\ \mu A$. For this measurement, collector was grounded with a large capacitor to eliminate any collector noise current being fed back to the base.

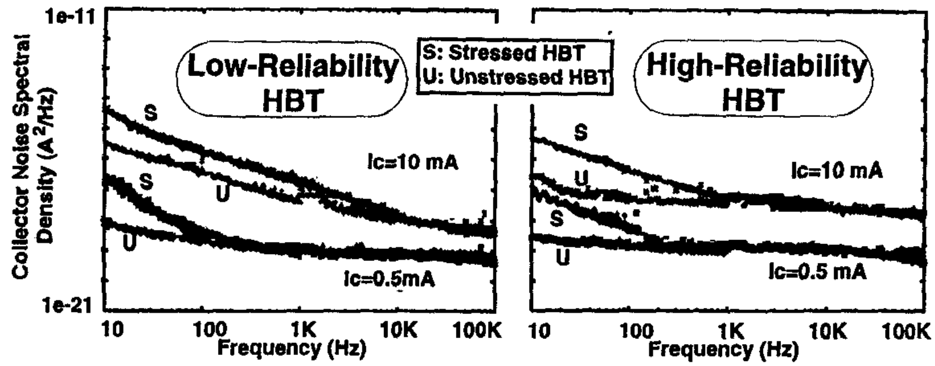

Fig. 2: Collector Noise Spectral Density of low and high-reliability HBTs before and after stressing.

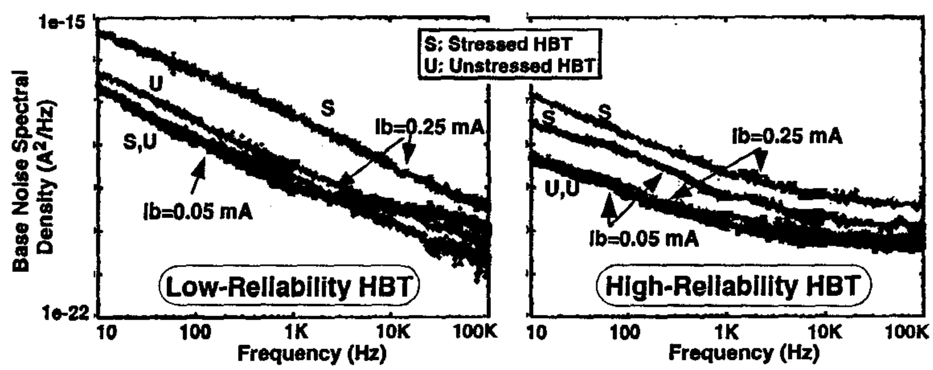

Fig. 3: Base Noise Spectral Density of low and high-reliability HBTs before and after stressing.

In both low and high-reliability HBTs, stress application increases the base noise spectral density. This increase is much more pronounced at higher base currents as shown by the results of Fig. 3. Another important observation is that the high-reliability HBTs show significantly lower base noise than low-reliability HBTs. In fact, the average base noise spectral density of high-reliability HBTs was found to be more than one order of magnitude lower than that of low-reliability HBTs at $f = 10\ Hz$. This establishes, for the first time, a significant selection criterion namely the correlation of the base noise of AlGaAs/GaAs single HBTs to their long-term reliability characteristics. On the other hand, as explained earlier on, the collector noise does not show any significant correlation with the HBT long-term reliability.

Low-temperature base and collector noise characterization was also performed on low and high-reliability HBTs. These tests were performed before and after stress application to permit a study of traps as a function of stress. Base and collector noise at different temperatures were plotted in Arrhenius plots to find activation energies of base-emitter and base-collector trap centers, respectively. For stressed and unstressed low-reliability HBTs, collector-base activation energies of 120 *meV* and

125 *meV* were found, respectively. Stressed and unstressed low-reliability HBTs had base-emitter activation energies of 140 and 149 *meV*, respectively. High-reliability HBTs did not show any significant generation-recombination noise in the base-emitter region while an activation energy of 207 *meV* was estimated for the collector-base region of unstressed high-reliability HBTs. The activation energy of the latter region for stressed high-reliability HBTs was estimated to be about the same (202 *meV*). Thus, stress *does not affect* the activation energy of generation-recombination centers in the base-collector region of high-reliability HBTs.

The average trapping time (τ) was evaluated from the Arrhenius plots. It was found that $\tau_{T=300K}$ in the base-collector region of low-reliability HBTs decreased by an 18% upon stress application. For high-reliability HBTs, the change in the average trapping time within the base-collector region was also insignificant. However, in the base-emitter region of low-reliability HBTs a decrease of more than two orders of magnitude occurred in the average trapping time at T=300 K due to stress application. This signifies a much higher density of traps in the base-emitter region of low-reliability HBTs upon stress application. Since the average trapping time of carriers can be related to the local defect density, the number of defects generated in the base-emitter appears to increase dramatically upon stress application. Thus, the defect density in the base-collector region does not vary significantly with stress application.

IV. Conclusion

In conclusion, the reliability of single heterojunction AlGaAs/GaAs HBTs appear to be correlated to their low-frequency noise characteristics. The low-frequency noise associated with the base-emitter region was found to be a more sensitive parameter than collector noise for predicting the reliability of these devices. The origin of the low-frequency noise was found to be independent of surface effects. The activation energies of generation-recombination centers estimated from low-temperature noise characterization were between 120 meV to 200 meV. Stress application did not change the activation energy of these traps but resulted in an increase of defect density in the base-emitter region.

Overall, the base noise and the corner frequency of the 1/f noise appear to be smaller for high-reliability HBTs. If used as a statistical method, this technique can provide a time-saving alternate to the bias and thermal stress reliability tests that are currently used in practice for HBT reliability screening.

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References

[1] M.A. Khatibzadeh and B. Bayraktaroglu, *IEEE Microwave Symposium Technical Digest,* 1990, pp. 993-996.

[2] B. Bayraktaroglu, *et al.*, *IEEE MTT-S Microwave and Millimeter-wave Monolithic Circuits Symposium Digest*, 1990, pp. 43-46.

[3] M.E. Hafizi, *et al.*, *GaAs IC Symposium Technical Digest*, Oct. 1990, pp. 329-332

[4] T. Henderson, *IEEE International Electron Device Meeting,* 1995, pp. 811-814.

[5] L.K.J. Vandamme, *IEEE Trans. Electron Devices*, Vol. 41, No. 11, Nov. 1994.

[6] J. Stich, *TWHM Workshop*, Sapparo, Japan, Aug. 1996.

[7] M. Tutt, *et al.*, *Proceeding of the 18th International Symposium on GaAs and Rel. Comp.*, 1991