Low-Frequency Noise Characterization of AlGaAs/GaAs HBT's

M. Borgarino, M. Peroni*, C. A. Cetronio*, F. Fantini

Dipartimento di Ingegneria dell'Informazione, Università di Modena e Reggio Emilia, and INFM, Via Vignolese, 905, 41100, Modena, Italy, borgarino.mattia@unimore.it

* Alenia Marconi Systems, Advanced Research & Technologies GaAs IC Group, Via Tiburtina, Km 12,400, 00131 Roma, Italy, mperoni@amsjv.it

In the present paper we evaluated the fabrication process of AlGaAs/GaAs Heterojunction Bipolar Transistors (HBT's) by means of low frequency noise characterizations carried out in the 100Hz-100kHz frequency range. We investigated the spectra of the base current fluctuations. The obtained results are compared with the data reported in the literature.

The fabrication technology and the experimental set-up are briefly described.

INTRODUCTION

Even if the term Low Frequency Noise (LFN) is often associated to physics, it represents a useful and flexible tool for engineers. It finds applications in several fields as the evaluation of technological processes (1-4), the device modeling for microwave design (5,6), and the reliability physics (7,8).

In the present work, we investigated the quality of AlGaAs/GaAs Heterojunction Bipolar Transistors (HBT's) fabricated by Alenia Marconi Systems. We studied the spectra of the base current fluctuations and their amplitude dependence on the transistor bias point.

The paper is organised as in the follows. The first and second sections describe the HBT fabrication process and the LFN experimental set-up, respectively. The third section presents the obtained spectra and their comparison with the literature. The fourth section ends the paper by summarising the main findings.

FABRICATION PROCESS

The epitaxial structure of the investigated devices is reported in Table I. The base layer was Carbon doped, to improve device reliability (9). The devices were fabricated using the following Monolithic Microwave Integrated Circuits technology. After multiple Deuterium implantation for active areas isolation, emitter contact has been patterned using Ti/Pt/Au metal deposition. The emitter metallization has been used for self aligned emitter mesa process down to the emitter AlGaAs layer surface, prior by ion beam etching to remove the InGaAs contact layer, and subsequently by GaAs wet etching using $NH_4OH:H_2O_2$ solution, selective to both AlGaAs and InGaAs.

Then the Pt/Ti/Pt/Au base contact has been defined by lift-off, after AlGaAs layer wet etching on the opened areas and subsequent metals deposition, thus forming a not self aligned E-B scheme with an AlGaAs passivation ledge between the contacts to reduce surface leakage current (10). Collector contact has been formed after sub-collector layer exposition by wet etching, AuGe/Ag/Au metal deposition and subsequent 430C°x30s Rapid Thermal Annealing alloying process. Overlay, Gold plated interconnections, 60µm thinning, via holes formation and back metallization completes the wafer fabrication.

Table 1
Epitaxial Structure

Thickness [A]	Composition	Doping [cm^{-3}]
300	$In_{0.5}Ga_{0.5}As$	$n^{+}\ 2\cdot 10^{19}$
300	GaAs? $In_{0.5}Ga_{0.5}As$	$n^{+}\ 2\cdot 10^{18-19}$
2000	GaAs	$n^{+}\ 2\cdot 10^{18}$
300	$Al_{0.25}Ga_{0.75}As$? GaAs	$n^{+}\ 2\cdot 10^{18}$
500	$Al_{0.25}Ga_{0.75}As$	$n\ 5\cdot 10^{17}$
1000	GaAs	$p^{+}\ 2.5\cdot 10^{19}$
4000	GaAs	$n^{-}\ 2\cdot 10^{16}$
8000	GaAs	$n^{+}\ 2\cdot 10^{18}$

LFN EXPERIMENTAL SET-UP

Since the investigation of the spectra of the base current fluctuations (S_{IB}) is the widest employed characterization approach adopted when the quality of a technological process has to be assessed (1-4), an experimental set-up allowing to characterize the base current LFN has been assembled. Figure 1 briefly depicts the employed experimental set-up. The base current fluctuations are amplified by a low noise EG&G 5182 Transimpedance (TA), set on a 10^{-6} A/V sensitivity, and AC connected to the input (base) of the Device-Under-Test (DUT) through a high value capacitor C. The amplified fluctuations are processed by a dynamic signal analyser (SR785). The set-up measures directly the base current fluctuations on the base side without adopting a multiple-impedance-like approach (1,11). This approach requires to close the DUT input on a high value resistor, making the measured spectrum on the DUT output (collector) dependent on the transfer function from the DUT input to the DUT output, that should be measured, increasing, therefore, the characterization time.

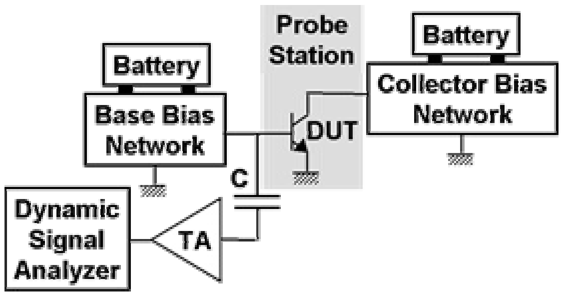

Figure 1: sketch of the experimental set-up.

In addition, it leads to measure the base current fluctuations superimposed to the collector current fluctuations and to the cross-spectrum between the base and collector current fluctuations. This point is overcome in the literature by assuming that the base current noise contribution to the output noise spectrum is the dominant one. In any case, the direct approach avoids this trouble. Moreover, thanks to the use of the TA, the base current fluctuations have been directly measured and not after having been transformed in voltage fluctuations on a resistor. This offers the advantage of making the measurement very much less sensitive to the presence of load non-idealities.

In order to avoid the 50Hz network interferences, both the DUT and the TA were biased using accumulators.

All the DUT characterisations were carried out at room temperature and at wafer level using a microwave probe station equipped with beryllium-copper coplanar probes with a pitch of 150µm.

Before LFN characterizing the DUT, the TA has been calibrated in terms of equivalent input referred noise voltage and current generators (12). We found that the input referred current and voltage noise generators are essentially constituted of white noise with a magnitude of about $2\,10^{-24}$ A^2/Hz and 10^{-17} V^2/Hz, respectively. The voltage noise source magnitude was found in agreement with the value already reported in the past (13).

Figure 2 compares the theoretical magnitudes of the equivalent current thermal noise spectra of several resistors with the experimental values obtained after the TA calibration. A good agreement was obtained down to about 10^{-25} A^2/Hz.

EXPERIMENTAL DATA AND DISCUSSION

The device quality has been studied through the 1/f noise figure-of-merit ($K_{1/f}$), which allows to compare DUT's fabricated with different technologies, different sizes, and characterized at different bias points (14):

$$S_{IB} = K_{1/f} \frac{I_B^{\gamma}}{A_E f} \tag{1}$$

where I_B is the base bias current, A_E is the emitter area and f is the frequency. Rigorously speaking, eq. (1) could be applied only if γ=2. Before applying eq. (1) to the HBT's under investigation, γ was thus extracted by varying I_B between 40µA and 80µA. Figure 3 reports the measured base current noise spectra. The black curves are the experimental data and the white curves are the

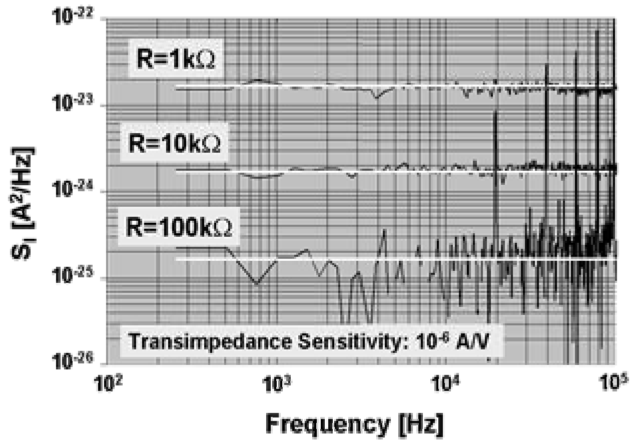

Figure 2: comparison between theoretical (black lines) and experimental (black curves) magnitudes the thermal noise in several resistors measured at room temperature.

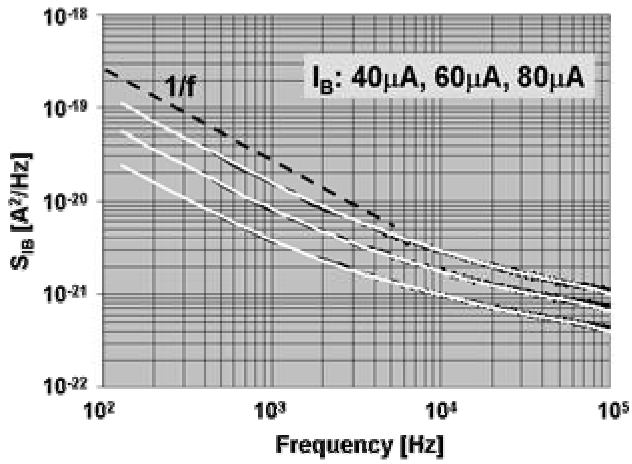

Figure 3: spectra of the HBT base current fluctuations for three different values of the bias base current.

numerical de-convolution based on the following expression:

$$S_{IB} = 2qI_B + \frac{k}{f} + \frac{k_{GR1}}{1+\left(\frac{f}{f_{CGR1}}\right)^2} + \frac{k_{GR2}}{1+\left(\frac{f}{f_{CGR2}}\right)^2} \quad (2)$$

accounting for the white shot noise component ($2qI_B$; q is the elementary charge), for one 1/f noise component (k is the coefficient of this component), and for two lorentzian components exhibiting characteristics frequencies f_{CGR1} and f_{CGR2} (k_{GR1} and k_{GR2} are the corresponding coefficients of these two components). We found that lower characteristic frequency was about 12kHz and the higher one about 165kHz.

Figure 4 shows the dependence of S_{IB} measured at 100Hz on I_B. The open circles are the experimental values and the solid curve is the fit. It was found γ =2.1 and this value was considered close enough to 2 to allow the use of eq. 1. From this equation we extracted a value of $K_{1/f}$ equal to about $9.2 \cdot 10^{-8}$ μm^2.

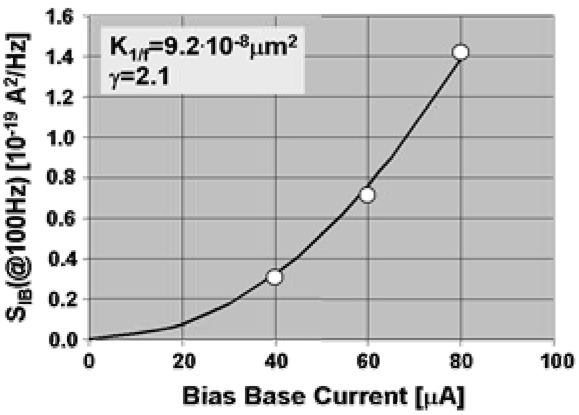

Figure 4: dependence of the magnitude of the base current fluctuations measured at 100Hz on the bias base current. The open circle are the experimental data and the black line is the numerical fit.

Figure 5 compares this value with the data reported in the literature during the last decade for different HBT technologies. The close circles are SiGe HBTs, the open triangles are InP HBT's, and the closed squares are GaAs HBT's. We can observe that the AlGaAs/GaAs HBT's investigated in the present work are well aligned with those fabricated by other companies and/or research laboratories.

In Figure 5 dashed eye-lines are traced for each technology. It is possible to observe that the SiGe HBT's exhibit the most low magnitude of noise while the GaAs HBT's are the most noisy technology.

Figure 5 points out also that for the III-V compound semiconductor HBT technology, the InP choice allows less noisy HBT's.

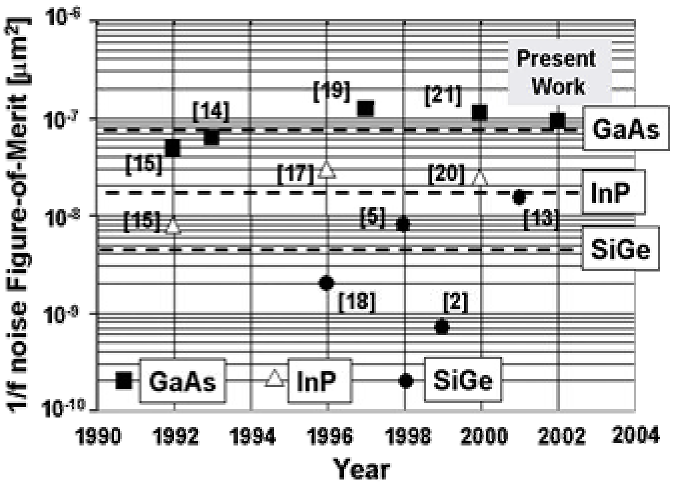

Figure 5: comparison in terms of 1/f noise figure-of-merit between different HBT technologies.

CONCLUSIONS

AlGaAs/GaAs HBT's fabricated in Alenia Marconi Systems (Roma, Italy) have been characterized at wafer level in terms of low frequency noise. In particular, we investigated the spectra of the base current fluctuations.

We found that the spectra result from the superimposition of a white shot noise component with one 1/f noise component and two lorentzian components exhibiting characteristics frequencies of 12kHz and 165kHz.

The investigation of the 1/f noise component dependence on the bias base current revealed that the magnitude of the base current fluctuation spectra exhibits a square-law dependence on the bias base current. This dependence allowed the extraction of the 1/f noise figure-of-merit that was found to be well aligned with the GaAs HBT technology data collected in the literature.

In summary, the use of the LFN characterisation tool demonstrated that the investigated AlGaAs/GaAs HBT's have been fabricated using a technological process, that well challenges in terms of fabrication quality these claimed by other GaAs companies and/or research laboratories.

REFERENCES

(1) J-H Shin, J Kim, Y Chung, J Lee, Y.Suh, K H Ahn and B Kim, *Low-Frequency Noise Characterization of Self-Aligned AlGaAs/GaAs Heterojunction Bipolar Transistors with a Noise Corner Frequency Below 3kHz*, IEEE Trans. on Electron Devices, Vol. 46 pp. 1604-1613, November 1998

(2) S Jouan, R Planche, H Baudry, P Ribot, J A Chroboczek, D Dutartre, D Gloria, M Laurens, O Llinares, M Marty, A Monroy, C Morin, R Pantel, A Perrotin, J de Pontcharra, J L Regolini, G Vincent and A Chantre , *A High-Speed Low 1/f Noise SiGe HBT Technology Using Epitaxially-Aligned Polysilicon Emitters,* IEEE Trans. on Electron Devices, Vol. 46 pp. 1525-1531, July 1999

(3) N Lukyanchikova, N Garbar, M Petrichuk, J F W Schiz and P Ashburn, *The Influence of BF_2 and F Implants on the 1/f Noise in SiGe HBTs With a Self-Aligned Link Base*, IEEE Trans. on Electron Devices, Vol. 48 pp. 2808-1815, December 2001

(4) R Tang, J Ford, B Pryor, S Anandakugan, P Welch and C Burt, *Extrinsic Base Optimization for High-Performance RF SiGe Heterojunction Bipolar Transistors,* IEEE Electron Device Letters, Vol. 18 pp. 426-428, September 1997

(5) B van Haaren, M Regis, O Llopis, L Escotte, A Gruhle, C Mahner, R Plana and J Graffeuil, *Low-Frequency Noise Properties of SiGe HBT's and Application to Ultra-Low Phase-Noise Oscillators,* IEEE Trans. on Microwave Theory and Technique, Vol. 46 pp. 647-652, May 1998

(6) Z Ouarch, F Arlot, M Borgarino, M Prigent, L Bary and M Camiade, *Low Phase Noise, Fully Integrated Monolithic VCO in X Band Based on HBT Technology,* IEEE International Microwave Symposium, 20-25 May, 2001

(7) S Mohammadi, D Pavlidids and B Bayraktaroglu, *Relation Between Low-Frequency Noise and Long-Term Reliability of Single AlGaAs/GaAs Power HBT's,* IEEE Trans. on Electron Devices, Vol. 47 pp. 677-686, April 2000

(8) M Borgarino, J Kuchenbecker, J-G Tartarin, L Bary, T Kovacic, R Plana, F Fantini and J Graffeuil, *Hot Carrier Effects in Si-SiGe HBTs,* IEEE Trans. on Device and Materials Reliability, Vol. 1 pp. 86-94, June 2001

(9) F Ren, T R Fullowan, J Lothian, P W Wisk, C R Abernathy, R F Kopf, A B Emerson, S W Downey and S J Pearton, *Stability of carbon and beryllium-doped base GaAs/AlGaAs heterojunction bipolar transistors,* Appl. Phys. Lett., Vol. 59 pp. 3613-3615, December 1991

(10) W. Liu, J. S. Harris, *Diode Ideality Factor for Surface Recombination Current in AlGaAs/GaAs Heterojunction Bipolar Transistor,* IEEE Trans. on Electron Devices, Vol. 39 pp. 2726-2731, December 1992.

(11) J A Babcock, D K Schroder, W-L M Huang and J M Ford, *Low-Frequency Noise in TFDOI Lateral N-P-N Bipolar Transistors,* IEEE Trans. on Electron Devices, Vol. 48 pp. 956-965, May 2001

(12) C-Y Chen and C-H Kuan, *Design and Calibration of a Noise Measurement System,* IEEE Trans. on Instrumentation and Measurement, Vol. 49 pp. 77-82, February 2000

(13) L Bary, M Borgarino, R Plana, T Parra, S J Kovacic, H Lafontaine and J Graffeuil, *Transimpedance Amplifier-Based Full Low-Frequency Noise Characterization Se-tup for Si/SiGe HBTs,* IEEE Trans. on Electron Devices, Vol. 48 pp. 767-773, April 2001

(14) L S Vempati, J D Cressler, J A Babcock, R C Jaeger, D L Harame, , *Low-Frequency Noise in UHV/CVD Epitaxial Si and SiGe Bipolar Transistors,* IEEE Journal of Solid-State Circuits, Vol. 31 pp. 1458-1467, October 1996

(15) N Hayama and K Honjo, *1/f Noise Reduction in Self-Aligned AlGaAs/GaAs HBT with AlGaAs Surface Passivation Layer*, IEEE Trans. on Electron Devices, Vol. 39, pp. 2180-2182, September 1992

(16) T G M Kleinpenning and A J Holden, *1/f Noise in n-p-n GaAs/AlGaAs Heterojunction Bipolar Transistors: Impact of Intrinsic Transistor and Parasitic Series Resistances*, IEEE Trans. on Electron Devices, Vol. 40, pp. 1148-1153, June 1993

(17) A K Kirtania, M B Das, S Chandrasekhar, L M Lunardi, G J Qua, R A Hamm and L-W Yang, *Measurement and Comparison of 1/f Noise and g-r Noise in Silicon Homojunction and III-V Heterojunction Bipolar Transistors*, IEEE Trans. on Electron Devices, Vol. 43, pp. 784-792, May 1996

(18) J D Cressler, L Vempati, J A Babcock, R C Jaeger and D L Harame, *Low-Frequency Noise Characteristics of UHV/CVD Epitaxial Si- and SiGe-base Bipolar Transistors,* IEEE Electron Device Letters, Vol. 17, pp. 13-15, January 1996

(19) S Jarrix, C Delseny, F Pascal and G Lecoy, *Noise correlation measurements in bipolar transistors. I. Theoretical expressions and extracted current spectral densities*, Journ. Appl. Phys., Vol. 81, pp. 2651-2664, June 1997

(20) M Borgarino, R Plana, M Fendler, J P Vilcot, F Mollot, J Barette, D Decoster and J Graffeuil, *Low frequency noise behaviour of InP/InGaAs heterojunction bipolar waveguide phototransistors*, Solid-State Electronics, Vol. 44, pp. 59-62, January 2000

(21) P Ma, M F Chang, P Zampardi, P Canfield, J Sheu and G P Li, *Source Identification and Control of 1/f Noise in AlGaAs/GaAs HBTs by Using an On-Ledge Schottky Diode*, IEEE Electron Device Letters, Vol. 21, pp. 528-530, November 2000