Excess Noise in Microwave GaInP/GaAs Heterojunction Bipolar Transistors

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Abstract

Low-Frequency (L.F.) noise experiments are performed on n-p-n GaInP/GaAs heterojunction bipolar transistors. The results show that this device exhibit very attractive performance since we have obtained a value of current noise generator in the range of 10^{-23} A^2/Hz at 10 kHz with a noise corner frequency in the 20 kHz range. Investigations on geometry and bias influence have revealed the presence of surface recombination effects. Finally noise measurements performed on transmission line models show that the input noise voltage generator is due to g-r noise in the base access resistance with a 0.48 eV activation energy and to 1/f noise in the emitter access resistance of the device.

Introduction

Heterojunction bipolar transistors (HBT's) are finding wide acceptance for applications in microwave and millimeter wave sources. Since these circuits operate in a non-linear mode, up conversion of the low-frequency (L.F.) noise results in phase noise which introduces limitations in both analog and digital systems. Consequently a full understanding of the HBT noise properties is very useful on one hand for technological process improvements towards L.F. noise reduction and on the other hand for further investigations of the up conversion noise mechanism in non-linear circuits. Therefore present paper deals with the characterization and the location of L.F. noise sources in GaInP/GaAs HBT's. Section I addresses a summary description of the device fabrication and of the microwave performances of these transistors. In section II, we present low-frequency noise measurements performed on single emitter finger device. Finally, in section III the possible origin of excess noise in GaInP/GaAs heterojunction bipolar transistors are discussed.

I Device fabrication

The devices are grown by LP.MOCVD using a self aligned technology and the base layer is carbon doped to ensure a low p dopant diffusion into the emitter. The current gain of the device is in the range of 20 for different emitter sizes (2x30μm^2, 3x30μm^2, 3x20μm^2 or 2x20μm^2) and is only weakly dependant on the bias conditions since an appropriate passivation has been used to reduce the surface recombination. Concerning the RF performance, the devices feature a current gain cut-off frequency of 60 GHz and a maximum oscillation frequency of 90 GHz. However there is yet a lack of information concerning the L.F. noise in these devices and their ability to be used in high spectral purity microwave sources.

II L.F. noise measurements

Our experimental test-set [1] allows to determine the input noise voltage (e_n) and noise current (i_n) variations versus frequency (250 Hz to 100 kHz) including the correlation and the optimum noise input termination resistance with respect to the minimum noise figure using a multiple resistance technique [2] and an appropriate numerical procedure [3]. On wafer L.F. noise measurements were carried out on a single emitter finger device featuring 2x30 μm^2 geometry at I_b=160 μA, I_c=3.2 mA and V_{ce}=2 V. Input referred voltage and current noise spectra are shown in Fig.1.

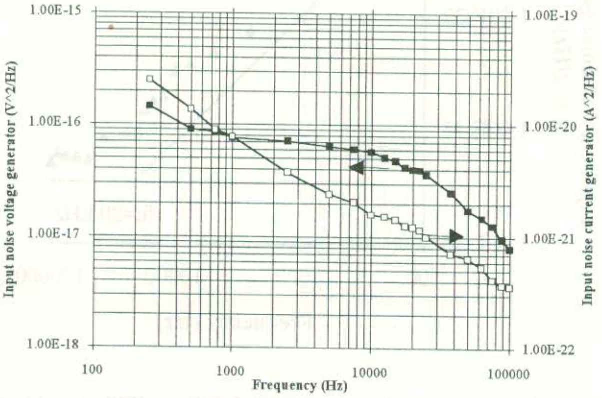

Figure.1 : Input noise voltage and current generators versus frequency for a 2 x 30μm^2 device at I_b=160 μA, I_c=3.2 mA and V_{ce}= 2 V

These spectra were analysed assuming that the noise was the sum of 1/f, g-r and white components. Concerning voltage noise, the generation-recombination (g-r) noise was the major excess noise source. Noise measurements at various ambient temperatures ranging 200 K to 300 K allow to observe the variations of the g-r noise corner frequency ($1/2\pi\tau$). Fig.2 shows the Arrhenius plots of τT^2 versus 1000/T and it demonstrates that the process exhibit an activation energy of 0.48 eV. Deep traps in GaAs related to impurities diffusion could therefore be invoked [4].

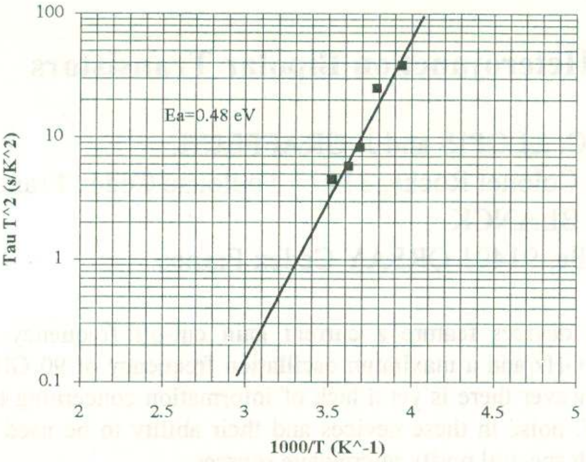

Figure 2 : Arrhenius plot versus 1000/T for 2 x 30 μm^2 device

The input referred noise current is dominated by an 1/f noise source. The g-r noise in the 10 kHz range was detectable but not dominant. The noise corner frequency where the excess noise amplitude becomes equal to the white noise amplitude ($2qI_b$) is typically below 1 MHz and can be as low as 20 kHz as it is shown in Fig.3 which is among the best value ever recorded.

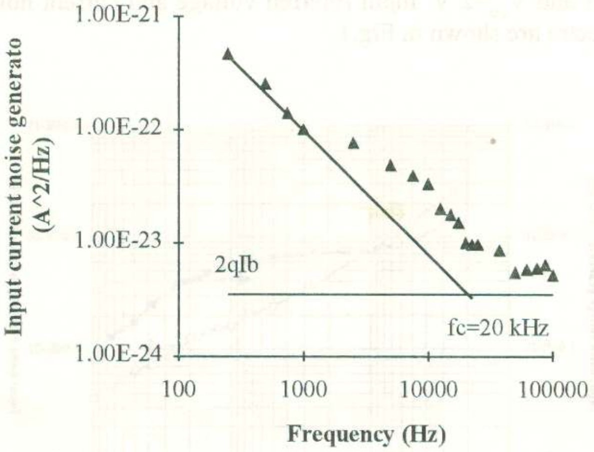

Figure 3 : Current Noise spectrum of GaInP/GaAs HBT at I_b=11µA, I_c=220 µA and V_{ce}=2 V

An other important data is the observed correlation between the two noise generators. The optimum noise resistance (referred to as R_{opt}) is defined by as:

$$R_{opt} = \sqrt{\frac{\overline{e_n^2}}{\overline{i_n^2}}} \qquad (1)$$

The correlation resistance (referred to as R_{cor}) is defined by :

$$R_{cor} = \frac{\Re\left(\overline{e_n i_n^*}\right)}{\overline{i_n^2}} \qquad (2)$$

where $\Re(e_n i_n^*)$ is the real part of the correlation. The variations of R_{opt} and R_{cor} versus frequency are shown in Fig.4.

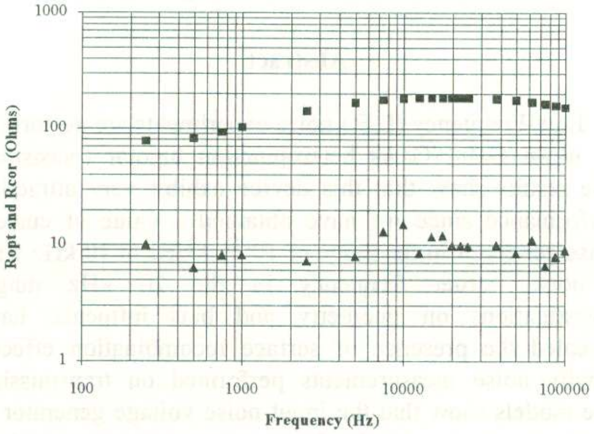

Figure 4 : Optimum noise resistance (■) and correlation resistance (Δ) for 2x30 µm² device

It can be seen that R_{opt} is in the range of 100 Ω which means that the optimum noise level is obtained for this input resistive termination and that for higher resistive values the major excess noise source will be the current noise generator. This value is an order of magnitude larger than R_{cor} which denotes a poor correlation between the input referred noise voltage (e_n) and current (i_n) generators. The correlation resistance provides us with the value of the distributed base resistance $r_{bb'}$ which in our case is smaller than 10 Ω.

This behavior indicates that the physical mechanisms which produces noise voltage and noise current are different and further investigations about their possible different origins are needed.

III Origin of excess noise sources

In order to determine the origin of the excess noise in these devices, we have performed L.F. noise measurements for various bias base current ranging 50 µA to 550 µA. The evolution of the input current noise generator at 10 kHz versus base current is reported on Fig. 5.

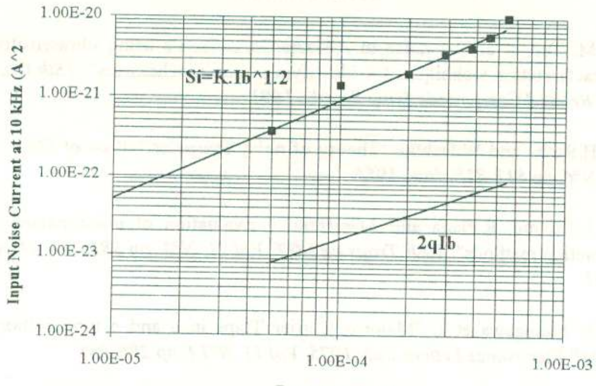

Figure 5 : Evolution of current noise generator at 10 kHz versus base current ranging 50 µA to 500 µA

The results indicate that $S_{in} \propto I_b^{1.2}$ which denotes the occurence of surface recombination effects. To confirm this result, noise measurements on three devices with different emitter geometries as referred in Table 1 were carried out.

Device	W (µm)	L(µm)	P/A
A1	2	30	1.06
A2	3	30	0.73
A3	2	20	1.1

Table 1

We have reported the evolution of the minimum noise figure versus frequency for the devices A1, A2 and A3 on Fig.6. Devices were biased at a constant collector current density (J_c=5.10^3 A/mm^2).

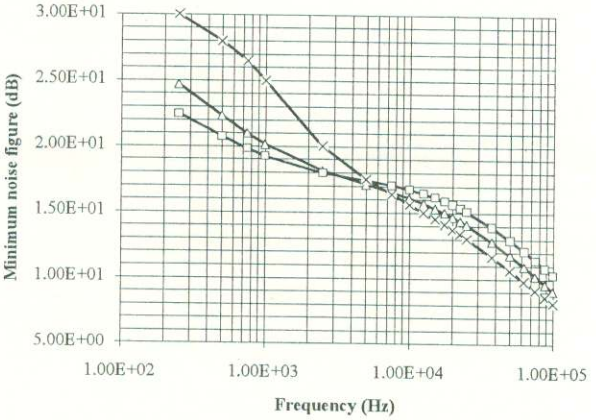

Figure 6 : Minimum noise figure versus frequency for the devices A1 (Δ), A2 (□) and A3 (x)

The results indicate that at very low frequency, the devices which exhibit the higher ratio P/A feature the highest noise level due to recombination surface effects on the periphery of the emitter of the device. In the range of 10 kHz, the bump on the spectra which is related to a trapping-detrapping process is enhanced for the device A2 featuring the highest W value. A leakage current and a recombination effect at the tip of the emitter finger could be invoked. Results indicate that in spite of a surface passivation layer the surface recombination is reduced but not completely eliminated.

In heterojunction bipolar transistor, the parasitic resistances play an important role [5,6] on the device noise level and an accurate evaluation of their contribution is therefore needed. We have performed extra noise measurements on p+ GaAs, n+ GaInP epitaxial planar resistors (60x100 and 60x50 µm^2 Transmission Line Models) which represent respectively the base and the emitter access resistances. Noise spectra observed in p+ GaAs are displayed on Fig.7 for various bias current values.

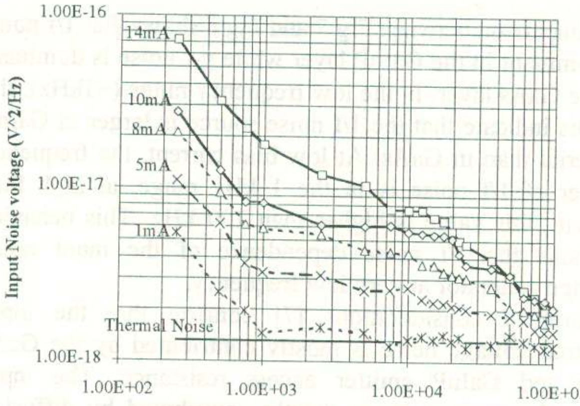

Figure 7 : Input noise voltage observed in p+GaAs transmission line model biased at different current values

Fig.7 shows that at low bias current, the major excess noise source is an 1/f noise but at high current, an extra g-r noise source occurs due to a trapping-detrapping effect in the GaAs and it damages the overall noise level. By example the 1/f noise corner frequency is in the range of 1 kHz and at high current, this value increases up to 100 kHz. This behavior plays an important role in microwave devices since they are biased at very high base current densities because of their small geometries dimensions and it explains the frequency dependence of the input noise generator voltage of the GaInP/GaAs HBT. The noise spectra observed on a n+ GaInP Transmission Line Model versus bias current are reported on Fig.8.

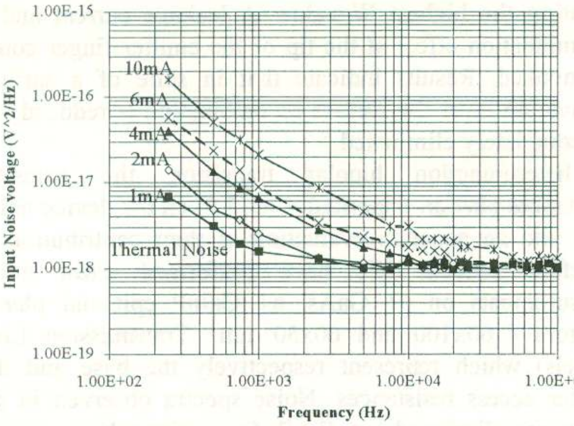

Figure 8 : Input Noise Voltage spectra of GaInP Transmission Line Model versus bias current ranging 1mA to 10 mA

A comparison between Fig.7 and Fig.8 shows that 1/f noise is dominant in the GaInP layer while g-r noise is dominant in the GaAs layer. In the low frequency range (<1kHz), the results indicate that the 1/f noise source is larger in GaInP material than in GaAs. At low bias current, the frequency corner of 1/f noise is in the 1 kHz range, at high bias current, this value is higher than 100 kHz. This behavior explains the 1/f noise dependence of the input noise voltage generator at very low frequency.
Theoretical considerations [7] confirm that the input referred voltage noise is mostly contributed by the GaAs base and GaInP emitter access resistance. The input referred current noise is mostly contributed by diffusion noise or dominant 1/f noise sources in the GaInP emitter-base space-charge region.
Moreover, since these two processes are not physically related, a strong correlation between the two input referred noise generators is not observed.

IV Conclusion

Our results provide evidence that GaInP/GaAs HBT's have potentialities for providing low L.F. noise since actual devices exhibit corner noise frequencies in the 100 kHz range which is among the best result ever reported. Two correlated input referred noise generators (voltage and current) are needed to account for the observed noise behavior. The noise voltage at usual working current densitiy is mostly of g-r type (0.48 eV activation energy) and is produced in the resistive parts of the device (emitter and base). The noise current mostly takes place at the emitter-base transition region. Additional investigations about device geometry and bias influence on noise show that the noise level of these devices is affected by surface recombination effects. We therefore expect that further L.F. noise reductions will be obtained in next generation devices to reduce the surface recombination effect and the excess noise sources in the resistive parts of the device.

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This work has been supported by the commission of the European Communities through the 5032 'AIMS' ESPRIT project