Low-frequency noise properties of GaInP/GaAs/GaInP DHBT's

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Abstract : This paper presents the low frequency noise of double heterojunction bipolar transistor (DHBTs) based on GaInP/GaAs/GaInP system. From static measurements, we can observe that both surface recombination along the emitter finger and bulk recombination in the extrinsic base region exist in these structure. S parameters measurements show very interesting microwave capabilities with cut-off frequency and maximum oscillation larger than 30 GHz. Concerning the noise properties, the results indicate that both 1/f and generation-recombination are present in DHBT. Both the input noise current and input noise voltage is inversely proportional to the emitter length. The inspection of the correlation between the noise generators reveals that the resistive parts of the device play a role on the overall noise component. Further, we have shown that the noise source at the output is not negligeable. Finally, a comparative noise study between emitter-up and collector-up DHBTs indicate that the noise current source is lower for collector-up DHBT than for emitter-up one related to a lower surface recombination rate.

Introduction

Heterojunction bipolar transistor (HBT) based on GaInP/GaAs material have shown interesting potentialities in term of power [1] and noise [2,3] performances at the microwave frequencies. Last years, we note the emergence of a new type of technology primarily dedicated to power microwave applications : the double heterojunction bipolar transistor (DHBT) [4]. In this paper, we propose to investigate for the first time the low-frequency (L.F) noise properties of DHBT's based on GaInP/GaAs/GaInP structure in order to evaluate the capabilities of this technology for low phase noise microwave applications.

In section I, we present a brief view of the double heterojunction bipolar transistor (DHBTs) involved in our work both in emitter up and collector up configuration. Section II is related to static characterization while section III deals with the microwave properties of these devices. Section IV and V present the L.F noise behavior versus bias, emitter length and transistor topology (emitter-up and collector-up) of DHBTs. Finally section VI closes with the discussion and the prospects.

1- DHBT devices description

The DHBT samples are MOCVD GaInP/GaAs/GaInP technology from a highly carbon doped base The devices involved in this work feature 2 µm emitter width and different emitter length ranging from 20 µm to 50 µm. Self-aligned and not self-aligned technology are available. The cross section of emitter-up and collector-up DHBTs are presented on Fig.1 and Fig.2 respectively.

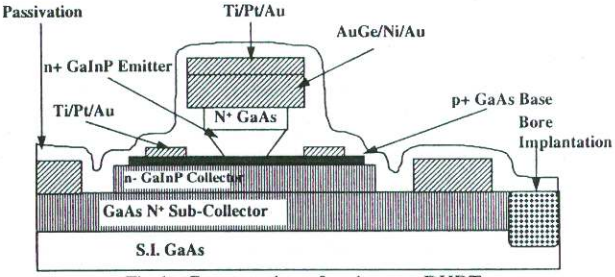

Fig.1 : Cross section of emitter up DHBTs

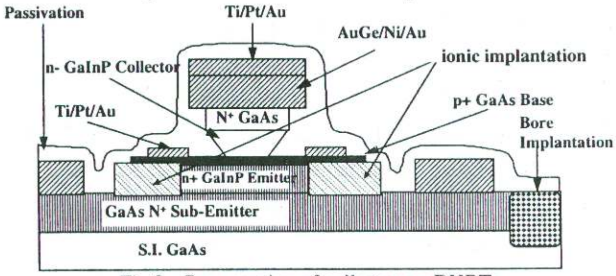

Fig.2 : Cross section of collector-up DHBTs

2- Static characterization

A full set of static characterization (including current gain, forward gummel plots measurements) have been carried out both on emitter-up devices featuring different emitter length and on collector-up transistors. We have plotted on fig .3 the evolution of the static current versus emitter length. The results indicate that it decreases when the emitter length increases which is related to surface recombination along the emitter finger. This behavior is well consistent with the ideality factor of the base current (obtained form forward gummel plots measurements) which increases with the emitter length (see the insert in fig.3).

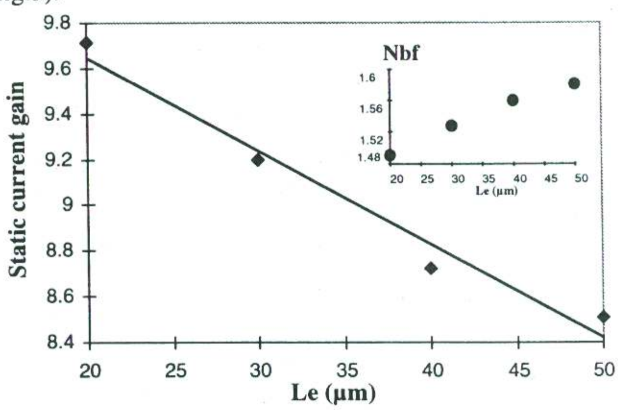

Fig.3 : Static current gain evolution versus emitter length for emitter-up DHBTs

Extra measurements have been performed both on self-aligned and not self-aligned technology and the results indicate that self-aligned technology exhibit a lower surface recombination rate but a larger bulk recombination due to a diffusion current between the base and the emitter contact. Concerning the collector-up configuration, we have noted that the devices exhibit a lower ideality factor of the base current which is related to a lower surface recombination rate. In the next section we presents the microwave properties of DHBts.

3- Microwave properties

In order to state on the microwave potentialities of this technology, on wafer scattering parameters measurements were performed from 40 MHz to 67 GHz. The results indicate cut-off frequency in the 30 GHz range and maximum oscillation frequency of 35 GHz and 45 GHz for emitter-up and collector-up topology respectively as indicated on Fig.4. These results indicate further that the collector-up configuration is well suited for microwave operation due to a lower collector-base capacitance.

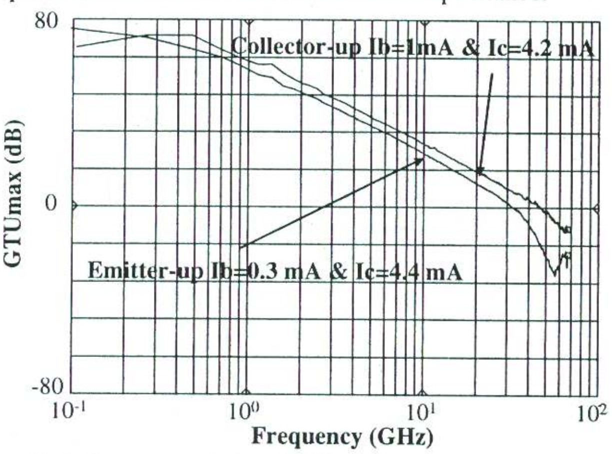

Fig4 : Frequency evolution of GTUmax both for emitter-up and collector-up DHBTs

4- L.F Noise properties of emitter-up DHBT's.

On wafer low-frequency noise characterization of DHBT is performed through the measurement of both the input noise current and noise voltage generators including their correlation from 250 Hz to 100 kHz. We first investigate the L.F noise emitter length dependence.

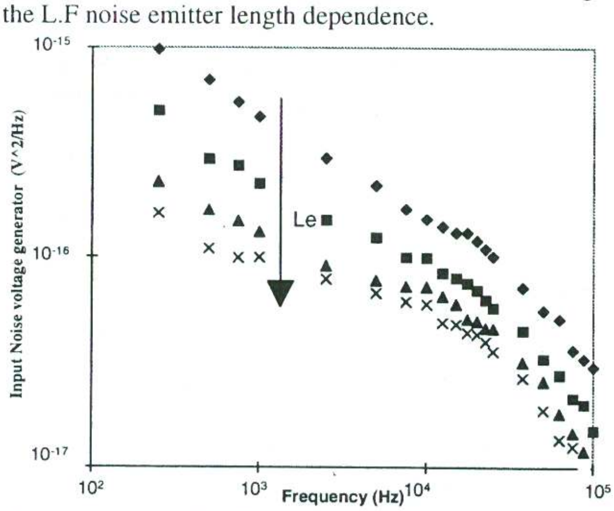

Fig.5 : Input noise voltage frequencies evolution versus emitter length for emitter-up DHBTs

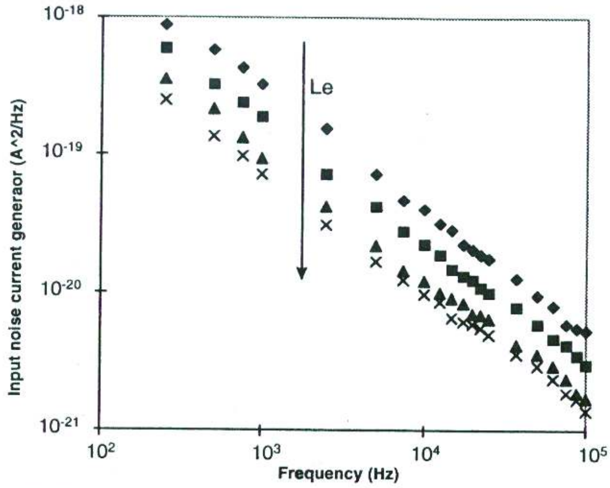

Fig.6 : Input noise current generator frequencies evolution versus emitter length for emitter-up DHBTs

On fig5 and 6, the frequencies evolution of the input referred noise voltage and noise current generators respectively are reported for not self-aligned devices featuring emitter length (L) ranging from 20µm to 50 µm. The samples were biased at a constant base current and at Vce=2V. The input noise voltage generator spectrum results from the superimposition of 1/f noise component (at low frequency) and a generation-recombination (g-r) noise component (at higher frequency). The data indicate that the 1/f noise magnitude increases when the emitter length decreases. This behavior is less pronounced for the g-r noise component which indicate that this excess noise component can be separate in two parts : one part located in the intrinsic base region (which is emitter length dependent) and the other part located in the extrinsic base region (which is emitter length not dependent). Concerning the input referred noise current generator, the data indicate that the major noise source is 1/f type and its magnitude increases when the emitter length decreases. In order to get a well understanding about the noise sources in these devices, we have investigate the correlation coefficient evolution versus emitter length as reported on Fig.7.

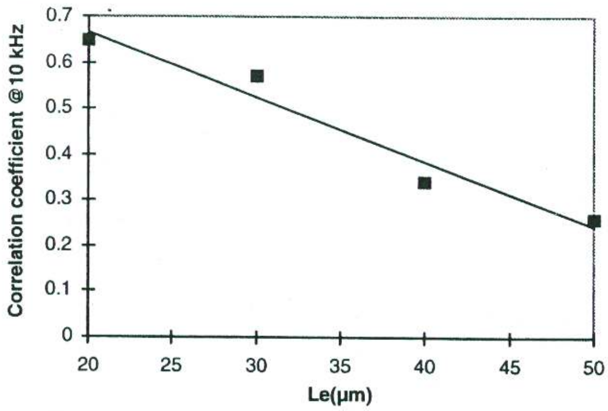

Fig.7 : Coefficient correlation evolution versus emitter length

The results indicate that the correlation coefficient decreases when the emitter length increases which is correlated with a decrease of both the emitter-base noise current source and the emitter resistance which leads to a more pronounced influence of noise generated in the resistive parts of the device. In order to investigate the noise impact of double heterojunction, extra noise measurements have been carried out versus different collector-emitter voltages (2V and 10V). The frequency evolution of the input referred noise current generator reported on fig.8 indicate that the 1/f noise magnitude decreases when the collector-emitter voltage increases.

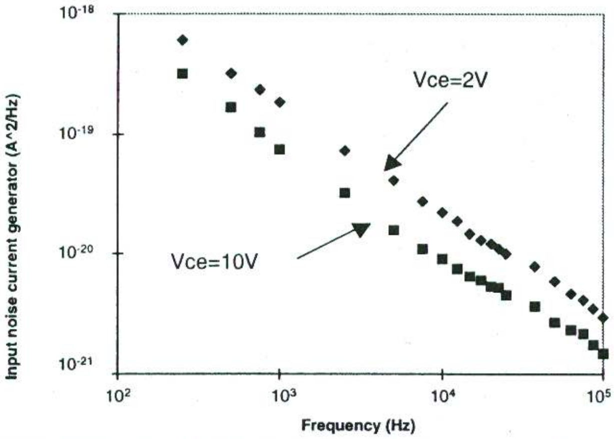

Fig.8 : Frequencies evolution of the input noise current versus collector-emitter voltage

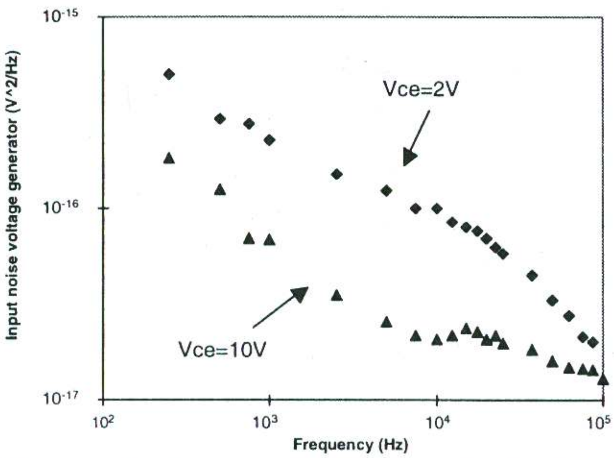

Fig.9 : frequencies evolution of the input noise voltage generator versus collector-emitter voltage

This behavior is consistent with an excess noise sources located on the collector side of the structure. Concerning the input noise voltage generator, the frequencies evolution versus collector-emitter voltage reported on Fig.9 indicate that both the 1/f noise and the generation-recombination noise decrease when the Vce voltage increase. This behavior confirms that Sic decrease with Vce leading to a decrease of the noise voltage generator. If we inspect the correlation coefficient evolution versus the collector-emitter voltage (see Fig.10), we observe that it is lower for the larger Vce value which is consistent with a lower noise current source and then a more pronounced impact of noise in the resistive parts of the transistor which has been confirmed by noise measurements on p+ GaAs and n+ GaInP Transmission Line Model (resistive samples) .

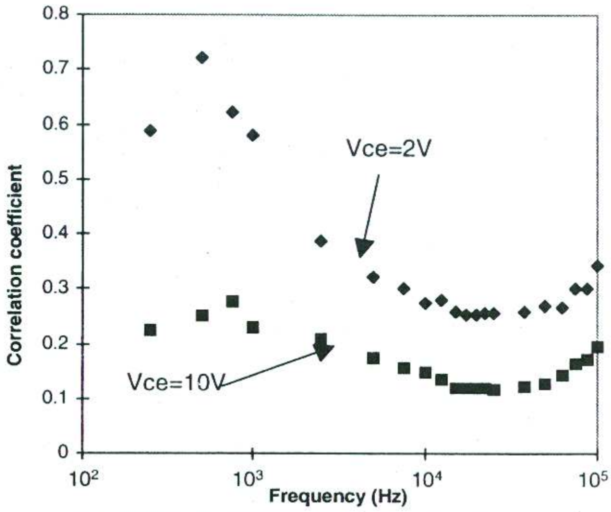

Fig.10 : Correlation coefficient evolution versus Vce voltage

Finally, we have studied the effect of the technology on the noise performance of the transistor. On fig.11, we have plotted the frequency evolution of the input noise current generator for self-aligned and not self-aligned technology. The spectra indicate that self-aligned devices are noisier than not self-aligned one. This behavior indicate that bulk recombination produce larger 1/f noise than surface one.

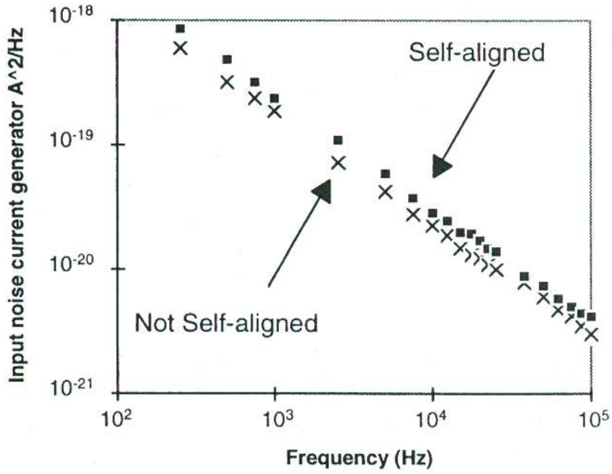

Fig 11 : Frequencies evolution of the input noise current generator versus self or not self aligned technology

5- L.F Noise properties of collector-up DHBT's

Finally, we present for the first time noise measurements on a new kind of HBT configuration called "collector-up" (with respect to the conventional one called "emitter-up"). On Fig.12, we have reported the frequency evolution of the input referred noise current generator for the two types of devices. The spectra indicate that the excess noise magnitude is lower for the "collector-up" configuration than for the "emitter-up" one which is probably associated with a decreasing of the recombination rate in the extrinsic base region. If we inspect the noise spectra shape when can observe that for emitter-up topology we have a generation-recombination noise component a low frequency

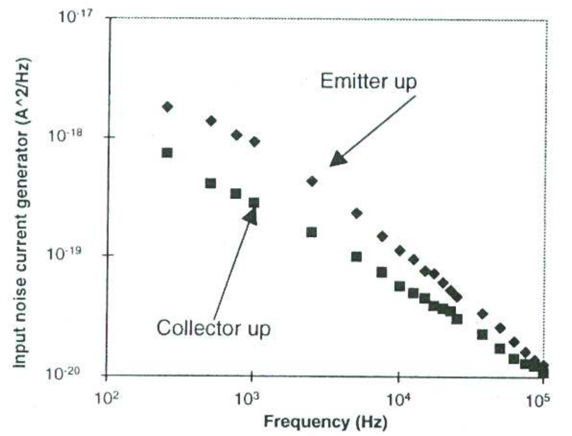

Fig.12 : Frequency evolution of the input noise current generator versus emitter-up or collector-up DHBTs

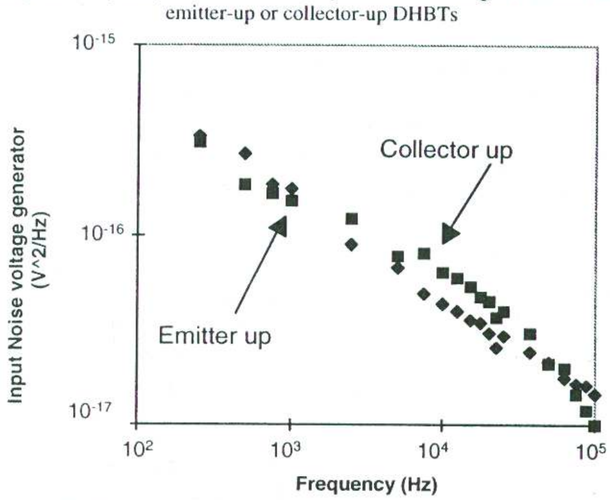

Fig.13 : Frequencies evolution of the input noise voltage generator versus emitter-up and collector-up topology

Concerning the frequencies evolution of the input noise voltage generator (see fig.13), the data indicate that collector-up topology leads to a larger generation-recombination component in the 10 kHz range which is probably related with a larger noise in the emitter access resistance. This behavior has been confirmed by noise measurements performed on emitter transmission line model (TLM).

6- Conclusion

In this paper, we present for the first time the low-frequency noise behavior of GaInP/GaAs/GaInP DHBTs featuring microwave performance larger than 30 GHz. From static measurements, we have shown that there are surface recombination along the emitter finger which did not lead larger 1/f noise current component Noise measurements indicate that both noise voltage and noise current are inversely proportional to the emitter length which is consistent with noise generated in the active region of the device. The inspection of the correlation indicate also that the resistive parts (base and emitter) play a role in terms of both 1/f and generation-recombination noise. Extra noise measurements indicate that excess noise sources versus the emitter-collector voltage are located at the collector side of the device. Finally, we have shown that self-aligned are noiser than not self-aligned one which indicate that bulk recombination in the extrinsic base region produce larger 1/f noise than surface noise in the extrinsic base region. "Collector-up" DHBT exhibit lower 1/f noise than "emitter-up" one which is consistent with a minimizing of the surface recombination in the extrinsic base region or at the surface along the emitter finger. Concerning the noise voltage behavior, a generation-recombination component appears for collector-up topology related to the emitter region. Finally, we can state that DHBTs exhibit interesting low-frequency noise behavior which can be improved through the passivation procedure and the emitter region for collector-up transistor.

Références :

[1]M.P.Mack et al "Microwave operation of high power InGaP/GaAs heterojunction bipolar transistor" Electronics Letters, June 1993,vol 29,n)12,pp1068-1069.

[2] R.PLANA et al "Low-frequency noise in self-Aligned GaInP/GaAs Heterojonction Bipolar Transistors" Electronics Letters, Vol 28, N°25, pp 2354-2356, 1992

[3] J.P.ROUX et al"Microwave Noise Performance of Self-Aligned GaInP/GaAs HBT" ESSDERC'94, Edimbourg, Septembre 1994 447-450

[4] W.Liu et al "1.5W-CW S-Band GaInP/GaAs/GaInP Double heterojonction Bipolar Transistor" IEEE Electron Device Letters, vol 15, n°6, June 1994, pp215-217.