THE INFLUENCE OF THE EMITTER ORIENTATION ON THE DC AND LOW FREQUENCY NOISE CHARACTERISTICS OF GaInP/GaAs HBTs

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ABSTRACT

The present paper focuses on the influence of the emitter orientation on the electrical characteristics of GaInP/GaAs HBTs. The investigation was carried out by means of DC and Low Frequency Noise (LFN) measurements in the 250Hz-100kHz frequency range. Samples featuring a conventional Carbon-doped base and an Indium-codoped/Carbon-doped base were available. We demonstrated that the emitter orientation has an impact both on the DC and LFN characteristics of HBTs. This behaviour has been attributed to piezoelectric effects and surface recombinations in the extrinsic base region around the emitter perimeter .

INTRODUCTION

It is known that the III-V compound semiconductors are polar and therefore exhibit a piezoelectric behaviour, as well summerized by Nye (1).
Ramirez et al. (2) demonstrate that the piezoelectric properties of the III-V semiconductors in MESFET devices give rise to the dependence of the threshold voltage on the orientation of the gate on the wafer. Lee et al. (3) report also the dependence of the saturation drain current on the gate orientation. Hishida and Ueda (4) demonstrate that in AlGaAs/GaAs HBT devices the piezoelectric effects lead to a dependence of both the DC current gain and the base current ideality factor on the orientation of the emitter on the wafer.
Rees (5) states that the electric fields associated with the piezoelectricity of the III-V compound semiconductors can be of the order of 0.1MV/cm, high enough to suggest the fabrication of novel devices, as lasers based on strained quantum well or integrated laser/waveguide modulators fabricated with the same vertical wafer design.
GaInP/GaAs HBT based dividers working at 17GHz, power MMIC with 3W output power at X-band, A/D converters, oscillators and broadband amplifiers have been already fabricated, making the GaInP/GaAs HBT a very interesting device in various application fields, as the wireless communications, the digital radars, the collision avoidance and satellite systems. But this kind of

devices suffer still from high recombination rates yealding poor reliability behaviour, which motivates technological efforts to improve their electrical performance.

In the present work, we report on the influence of the emitter orientation both on the DC characteristics and on the LFN performance, in the 250Hz-100kHz frequency range, of GaInP/GaAs HBTs.

SAMPLES AND EXPERIMENTAL

The investigation was carried out on two sets of devices featuring the same epitaxial structure, both fabricated through a double-mesa process and passivated through a SiN layer deposited by Plasma Enhanced Chemical Vapour Deposition. The sketch of the cross-section of the investigated devices is reported in Fig. 1. Both wafers employed for the fabrication of the HBTs were grown by Metal Organic Chemical Vapour Deposition and were perfectly identical except for the base layer.

Wafer A was grown with a conventional Carbon doped GaAs base layer while in the case of the wafer B, the base layer was co-doped with Indium, in order to reduce the mechanical strain induced by the large concentration of the base dopant ($5 \cdot 10^{19} cm^{-3}$). Nittono et al. (6) found that the Indium codoping improves the HBT reliability. The base dopant and the base thickness (120nm) were the same for the two wafers. All the investigated devices feature an emitter width (W_E) of 2μm and an emitter length (L_E) of 30μm. For each wafer, two emitter orientations were considered : [011] (conventional) and $[01\underline{1}]$.

All the characterizations were carried out on wafer by making use of a Cascade coplanar probe station. For the DC measurements, we used a HP4142 DC source/monitor. The LFN measurements were performed through the multiple resistance technique and using a Fast Fourier Transform sprectrum analyzer.

RESULTS

Figure 2 compares the DC current gains measured at a collector-emitter voltage of 2V versus the base current for A and B HBTs and for different emitter orientations. For a given emitter orientation, we can observe that the devices fabricated on the wafer A exhibit a higher DC current gain than those of wafer B.

On the other hand, for a given technology (A or B), we can note that the devices featuring the $[01\underline{1}]$ emitter orientation exhibit a higher DC current gain than those featuring the [011] orientation. In addition, it is worth pointing out that the differences in the DC current gain between A and B samples are more pronounced in the case of the [011] than in the case of the $[01\underline{1}]$ orientation.

Figure 3 compares the Gummel plots of typical wafer A HBTs featuring a different emitter orientation. In agreement with the previous data on the DC current gain, the base current is lower when the emitter is $[01\underline{1}]$ oriented. The ideality factors of the base current are 1.27 and 1.41 in the case of a [011] and $[01\underline{1}]$ orientation, respectively. The leakage currents are comparable.

Figure 4 compares the Gummel plots of typical wafer B HBTs featuring a different emitter orientation. Even in this case we found that the devices with the $[01\underline{1}]$ orientation exhibited the lowest base current, again in agreement with the previous DC current gain measurements. The ideality factors of the base current range around 1.20 and the leakage currents are comparable.

As similarly observed for the DC current gain, even for the Gummel plots, the differences in the base currents are more pronounced for B than for A samples.

In order to clear up the phenomenon, we investigated the influence of the emitter orientation on the LFN properties. Figures 5 and 6 show the spectra of the input noise current generators (S_I) for typical A and B HBTs, respectively. All the spectra result from the superimposition of a 1/f noise component, dominant at frequencies lower than 1kHz, and of a lorentzian component, dominant at

frequencies in the range of tens of kHz. For both the technologies, no differences in the 1/f noise component can be observed between devices featuring a different orientation of the emitter. On the other hand, it is easy to observe that the spectra exhibited a large difference in the lorentzian magnitude. Both the A and B samples featuring the [011] emitter orientation exhibit a higher magnitude of the lorentzian component. This behaviour is more pronounced for B than for A samples and it is associated with a higher noise magnitude for the former than for the latter.
Since the dependence of the input noise current generator on the bias base current I_B gives information about the bulk or surface nature of the noise sources, as reported by Plana et al. (7), the input noise current generator have been measured for different base currents ranging from 60μA to 230μA for all the samples. The 1/f and shot noise components were deembedded and the lorentzian component was studied in terms of the following power law expression :

$$S_I \propto I_B^m$$

Table I lists the obtained results. We can observe that the devices featuring the [01$\underline{1}$] emitter orientation exhibited lower values of m and that the dispersion of m factor with respect to the emitter orientation is more pronounced for B than for A HBTs.

DISCUSSION

We open the discussion of the experimental data by looking to the devices featuring the conventional oriented emitter [011].
We have previously observed that the B samples exhibit a lower base current ideality factor. Following the work of Liu and Harris (8), where it was demonstrated that the recombination in the base-emitter space-charge region gives rise to an ideality factor close to 2, we can state that the surface recombinations are more important in the B than in the A samples.
The same conclusion can be drawn by looking to the Table I showing that the B samples exhibited a higher m factor value. In the quoted work of Plana et al. (7), a value of m close to 2 was attributed to the surface noise sources. Therefore, also the higher value of m exhibited by the B samples suggests that in these HBTs the surface recombinations are more important than in the A HBTs. In point of fact, this conclusion agrees with the work of Borgarino et al. (9) carried out on devices featuring a conventional oriented emitter. In this work, it was found that the B samples suffer from a larger emitter-size effect associated with a larger surface recombination rate. Therefore the differences in the DC current gain between devices featuring the [011] emitter orientation (see Fig. 2) has to be ascribed to a difference in the surface component of the base current.
Now, we can discute the data concerning the devices featuring the tilted emitter [01$\underline{1}$].
Fig. 2 shows that the use of a [01$\underline{1}$] oriented emitter increases the DC current gain for both the two technologies. For each sample (A or B), this increase of the DC current gain is associated with a decrease of the lorentzian component in the spectrum of the input noise current generator (see Fig. 5 and 6). Since it is known that the lorentzian component is due to generation-recombination processes, the previous considerations carried out on devices featuring a conventional oriented emitter suggest that the change of the emitter orientation from [011] to [01$\underline{1}$] allow to fabricate devices suffering from a reduced surface recombination rate. Indeed, Table I shows that for each technology the change of the emitter orientation reduces the m factor. In addition, note that the values exhibited by the samples featuring the [01$\underline{1}$] emitter orientation are the same. These results demonstrate that the main contribution to the lorentzian component in the devices featuring the [011] oriented emitter is surface related. Moreover, Table I also indicates that the lorentzian component still present in the spectra of the input noise current generator of devices with the [01$\underline{1}$]

orientation emitter is probably located in the bulk (e.g. recombination in the space-charge region of the emitter-base junction).
From the physical point of view, the reduction of the surface recombination rate caused by the variation of the emitter orientation can be explained in terms of piezoelectric effects. Since the devices were fabricated through a double-mesa process, close to the emitter mesa there is a sharp variation of the vertical geometry of the device (see Fig. 1) leading to a mechanical strain in proximity of the emitter perimeter and giving rise to an electric field related with the piezoelectric properties of the III-V semiconductors, as already reported by Ishida and Ueda (4). It is known that the extrinsic base surface near the emitter perimeter is a critical zone for a HBT, because of defects turning out a pinning of the surface Fermi-level, that originates a saddle point in the conduction band edge profile, through which the electrons injected by the emitter can stream into the extrinsic base surface where they recombine, as well explained by Tiwari (10). Because of the device vertical geometry variation previously described, the piezoelectric field is located exactly in proximity of this critical region. The variation of the emitter orientation from [011] to [01$\underline{1}$] causes to tilt of 90° the orientation of the edge of the emitter mesa and this reverses the versus of the piezoelectric field, as pointed out by Ishida and Ueda (4). Therefore we propose that the dependence of the DC and LFN characteristics on the emitter orientation can be explained as follows.
When the emitter orientation is [011], the piezoelectric field is oriented so that it drifts the electrons towards the extrinsic base and therefore it enhances the surface recombination rate. On the other hand, when the emitter is tilted in the [01$\underline{1}$] orientation, the piezoelectric field drifts the electrons away from the edge of the emitter-mesa where the pinning of the surface Fermi-level occurs, reducing the surface recombination rate and yealding a higher DC current gain and a lower excess noise magnitude.

CONCLUSIONS

In this work, we have investigated two sets of GaInP/GaAs HBTs. The devices were available with two different orientations of the emitter : [011] and [01$\underline{1}$]. We demonstrated that the emitter orientation plays an important role in the rate of the recombination taking place at the surface extrinsic base region. In particular, we demonstrated that the use of the [01$\underline{1}$] emitter orientation leads to an increase of the DC current gain and to a decrease of the lorentzian component of the input current noise generator, which is important in the non-linear applications where the low frequency noise is directly up-converted into phase noise near the carrier.
The experimental results were explained by taking into account the surface recombination mechanism in the extrinsic base region and the piezoelectric properties of the III-V compound semiconductors.
We should further expect that the [01$\underline{1}$] emitter orientation leads to an improvement of the reliability of HBT samples thanks to a minimization of the recombination in the extrinsic base region.

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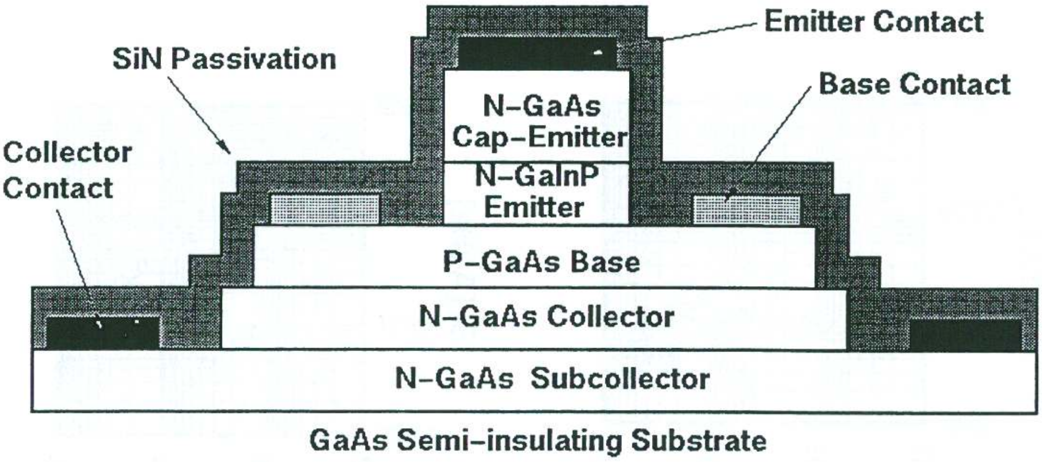

Figure 1 : sketch of the cross-section of the investigated GaInP/GaAs HBTs.

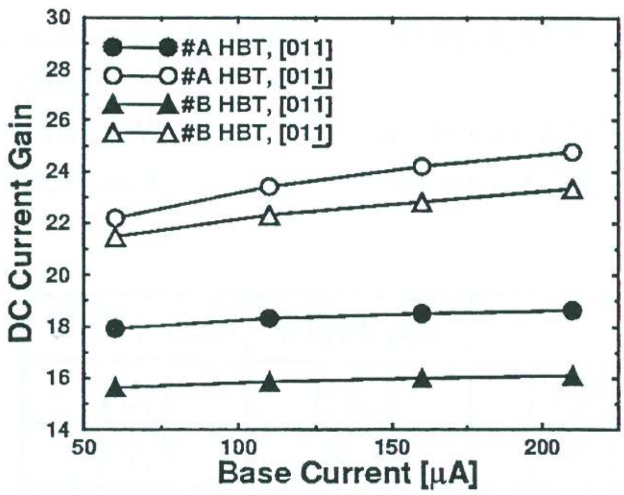

Figure 2 : DC current gain versus base current for A and B HBTs featuring different emitter orientations.

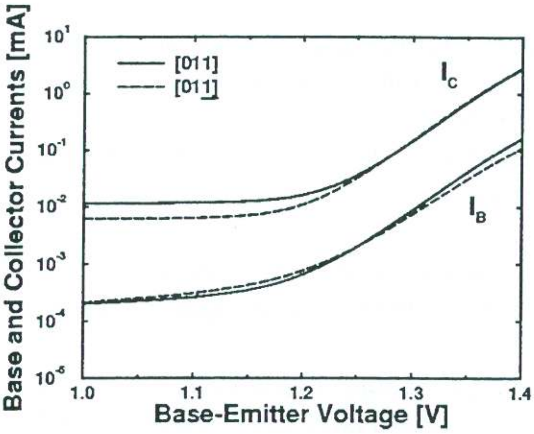

Figure 3 : Gummel plots for A HBTs.

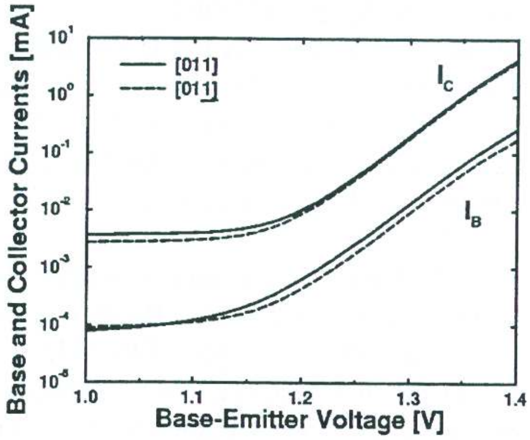

Figure 4 : Gummel plots for B HBTs.

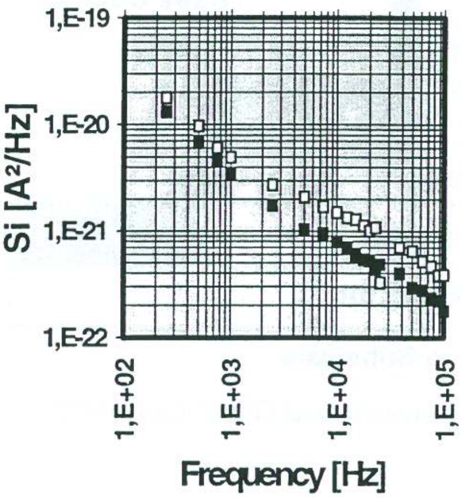

Figure 5: Input noise current generator
for A-HBTs.
White dots : [011] orientation.
Black dots : [01$\underline{1}$] orientation.

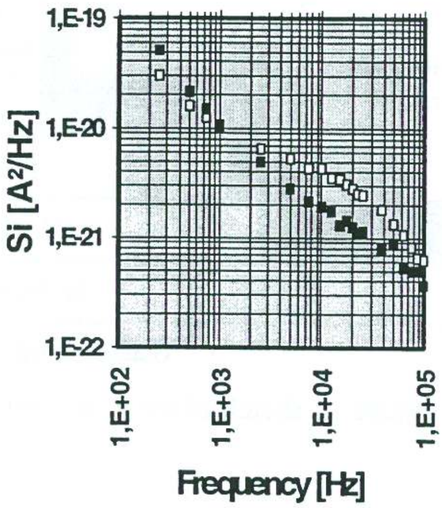

Figure 6: Input noise current generator.
for B-HBTs.
White dots : [011] orientation.
Black dots : [01$\underline{1}$] orientation.

	#A HBT	#B HBT
[011]	1,38	1,57
[01$\underline{1}$]	1,2	1,21

Table I : *m* factor for A and B HBTs fetauring different emitter orientation.