

LOW-FREQUENCY NOISE CHARACTERISTICS OF SELF-ALIGNED ALGaAs/GaAs HBT'S WITH A NOISE CORNER FREQUENCY BELOW 3 KHZ

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ABSTRACT

We have investigated the surface recombination and its 1/f noise properties of AlGaAs/GaAs HBT's as a function of the emitter-base structure and the surface passivation condition. It is found that the surface recombination 1/f noise can be significantly reduced by the heterojunction launcher of the abrupt junction with 30 % Al mole fraction emitter. The depleted AlGaAs ledge surface passivation further suppresses the surface recombination currents. Consequently, we have achieved a very low 1/f noise corner frequency of 2.8 kHz at the collector current density of 10 kA/cm². The dominant noise source of the HBT is not a surface recombination current, but a bulk current noise. This is the lowest 1/f noise corner frequency among the III-V compound semiconductor devices, and comparable to those of low-noise Si BJT's.

INTRODUCTION

Recently, the use of electrically abrupt emitter-base (E-B) junction HBT was suggested for the reduced 1/f noise [1]. The unpassivated HBT demonstrated a very low 1/f noise corner frequency of about 8 kHz, comparable to those of low-noise Si BJT's. Nevertheless, the dominant noise source for the HBT was still the residual surface recombination [1]. This suggests that the noise can be further reduced by applying the depleted AlGaAs ledge passivation technique [2]-[4]. To find the optimized HBT structure for the reduced 1/f noise, the surface recombination characteristics of HBT's have been investigated as a function of the grading of E-B junction, the Al composition in the emitter, and the surface passivation condition.

Table 1. HBT's Used For This Work

HBT	E-B Junction	Al Mole Fraction [%]	Base Thickness [Å]	Collector Current Ideality Factor
HBT A	Abrupt	30	1000	1.180
HBT B	Graded	30	1400	1.002
HBT C	Abrupt	20	1000	1.067

(HBT A', B', and C' are the passivated counterparts of HBT A, B, and C, respectively.)

Table 2. MOCVD Layer Structure For HBT A and A'

Layer	Thickness [Å]	Doping [cm ⁻³]
Cap	n ⁺ In _{0.5} Ga _{0.5} As	400
	n ⁺ In _x Ga _{1-x} As (x:0→0.5)	400
	n ⁺ GaAs	500
	n GaAs	700
Emitter	n Al _x Ga _{1-x} As (x:0.3→0)	300
	n Al _{0.3} Ga _{0.7} As	700
Base	p ⁺ GaAs	1000
Collector	n GaAs	4000
Subcollector	n ⁺ GaAs	6000

DEVICE STRUCTURE

Table 1 shows the device structures studied. To investigate the E-B junction effects on the surface recombination current and its related 1/f noise, we used the unpassivated Al_xGa_{1-x}As/GaAs HBT's with three different E-B structures: HBT A (abrupt/ x=0.3), HBT B (graded/ x=0.3), and HBT C (abrupt/ x=0.2). HBT A', B', and C' are the surface-passivated counterparts of HBT A, B, and C, respectively. Table 2 describes the MOCVD-grown layer structure for HBT A and A'. HBT B is identical to HBT A except 1400 Å thick base. HBT C is identical to HBT A except 20 % Al mole fraction emitter. The typical collector current ideality factors were 1.180, 1.002, and 1.067 for HBT A, B, and C, respectively. The nearly unity

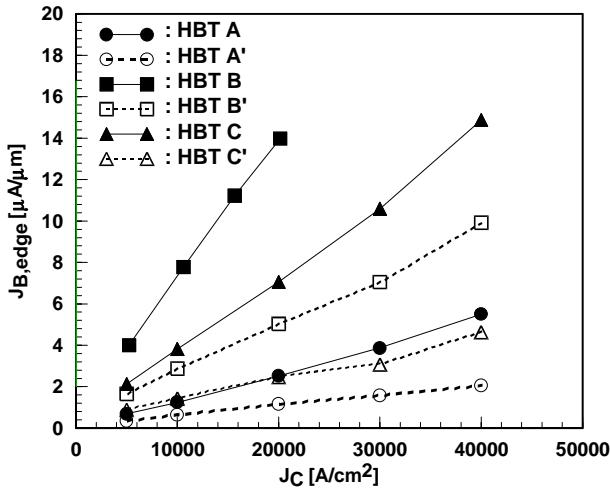


Fig. 1. Edge-emitter base current density ($J_{B, \text{edge}}$) .vs. collector current density (J_C) characteristics of HBT's

ideality factor of HBT B means that it has a graded E-B junction [5]. But, the ideality factors more than unity for HBT A and C mean that they have electrically abrupt E-B junctions and that the heterojunction launchers are effective for HBT A and C. Since the value of conduction band discontinuity (ΔE_C) for HBT A with 30 % Al mole fraction emitter is much larger than that for HBT C, HBT A is expected to have the strongest launching effect and therefore the smallest surface recombination current amongst the unpassivated HBT structures.

Fig. 1 shows the emitter-edge base current density ($J_{B, \text{edge}}$) .vs. collector current density (J_C) characteristics for the various HBT's, confirming our expectation. At $J_C = 10 \text{ kA/cm}^2$, the value of $J_{B, \text{edge}}$ for HBT B is $7.78 \mu\text{A}/\mu\text{m}$, which is much larger than $1.24 \mu\text{A}/\mu\text{m}$ for HBT A. Here, HBT A and B have 30 % Al emitters, but different base widths, and its effect should be examined. Generally, the thin base can reduce the surface recombination current. According to reference [3], $J_{B, \text{edge}} = J_C \cdot s \cdot W_B \cdot L_d / D_n \propto J_C \cdot W_B^2$, where s is the surface recombination velocity, W_B the base width, L_d ($\propto W_B$) the electron lateral diffusion length, and D_n the electron diffusivity in the base. From the relation, the $J_{B, \text{edge}}$ reduction factor is estimated to be about 2, which is much less than the measured factor of 6.3. Consequently, the thin base of HBT A does not play a major role in reducing the surface current. It is noteworthy that the $J_{B, \text{edge}}$ value of $1.24 \mu\text{A}/\mu\text{m}$ for the unpassivated HBT (HBT A) is, within our

knowledge, the lowest value among the unpassivated AlGaAs/GaAs HBT's. At $J_C = 10 \text{ kA/cm}^2$, the $J_{B, \text{edge}}$ reduction factors by surface passivation are 2.22, 2.71, and 2.73 for HBT A and A' pair, HBT B and B' pair, and HBT C and C' pair, respectively. Amongst the HBT structures, HBT A' has the lowest surface recombination current.

LOW-FREQUENCY NOISE CHARACTERISTICS

Since the 1/f noise of HBT is generated mainly from the base surface and E-B junction recombination currents, we have measured the base current noise spectra (S_{Ibe}). Fig. 2 shows the spectra for HBT A, B, and C with different E-B structures. At $J_C \approx 7 \text{ kA/cm}^2$, and $f = 10 \text{ Hz}$, we can observe that the magnitude of S_{Ibe} for HBT A is the lowest, as can be deduced from the surface current characteristics given by Fig. 1. This indicates that the 1/f noise of S_{Ibe} can be determined by the magnitudes of surface recombination currents. In addition, we can also observe that the magnitudes of the g-r noise plateaus for abrupt HBT's (HBT A and C) are much lower

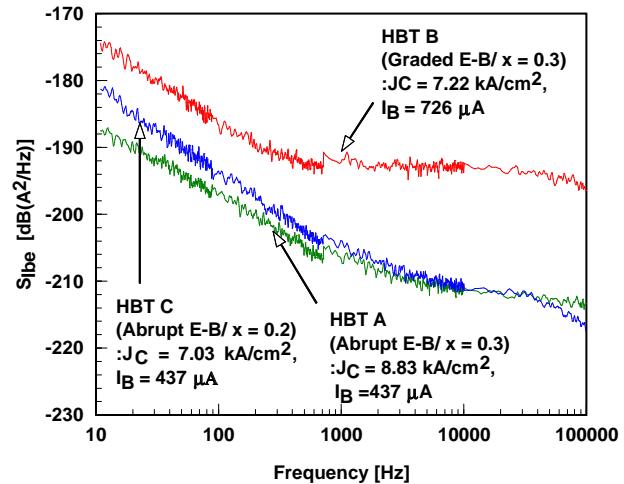


Fig. 2. Low-frequency base current noise (S_{Ibe}) spectra for the unpassivated HBT's with three different E-B structures: HBT A (abrupt E-B/ $x = 0.3$), HBT B (graded E-B/ $x = 0.3$), and HBT C (abrupt E-B/ $x = 0.2$)

Table 3. Corner Frequencies(F_C) At $J_C = 10 \text{ kA/cm}^2$

HBT's	HBT A	HBT A'	HBT B	HBT B'	HBT C	HBT C'
F_C [kHz]	6.5	2.8	55	7.7	11	5.5

than that of the graded HBT (HBT B). While the g-r noise plateaus of HBT A and C are about 5 dB larger than the shot noise floor of $2 q I_B$, that of HBT B is at least 20 dB larger than the noise floor. This very low g-r noise for the abrupt HBT's may be attributed to the suppression of E-B space charge region recombination current of the abrupt E-B junction[6]. To estimate the surface passivation effect on the 1/f noise and to evaluate the 1/f noise corner frequencies for various HBT structures, the S_{Ibe} spectra have been measured. Table 3 summarizes the measured corner frequencies for the HBT's. By passivating HBT's, the noise levels have been reduced by more than 5 dB. The passivated HBT with abrupt E-B junction and 30 % Al mole fraction emitter layer (HBT A') has a very low noise corner frequency of 2.8 kHz at the practical bias point of $J_C = 10 \text{ kA/cm}^2$. To our knowledge, this is the lowest noise corner frequency among the III-V compound semiconductor transistors at the practical bias point, and is comparable to that of low-noise microwave Si BJT.

Fig. 3 shows the $S_{Ibe}(10 \text{ Hz})$.vs. $I_{B, \text{edge}}$ for HBT's with various emitter sizes. Except for HBT A', the values of $S_{Ibe}(10 \text{ Hz})$ vary as proportional to only $I_{B, \text{edge}}^2$, independent of the emitter area (A_E), the emitter perimeter/ emitter area (P_E/A_E), the grading of E-B junction, the Al mole fraction of the emitter layer, and the surface passivation condition. This clearly supports that the dominant 1/f noise source for all the HBT's except for HBT A' is the extrinsic GaAs base surface recombination velocity fluctuation. Although all the HBT's except HBT A' have larger 1/f noise levels than HBT A', the noise corner frequencies are much lower than the previously reported values of about 100 kHz for AlGaAs/GaAs HBT's. In addition, our HBT's show very clear bias dependency of $S_{Ibe}(10 \text{ Hz}) \propto I_{B, \text{edge}}^2$, unlike the other HBT's. This indicates that the recombination-related 1/f noise sources other than the base surface recombination 1/f noise source are not significant for our HBT's. Therefore, the low corner frequencies for our HBT's can be attributed partly to their low recombination-related bulk noise sources such as the hetero-interface and E-B surface recombination noise sources. Meanwhile, for the HBT A', $S_{Ibe}(10 \text{ Hz})$ is not proportional to $I_{B, \text{edge}}^2$. This means that the noise source for HBT A' is not located at the emitter periphery, but at the bulk area under the emitter. Generally, the spatially uncorrelated bulk 1/f noise source ($S_{IB, \text{bulk}}$), which is

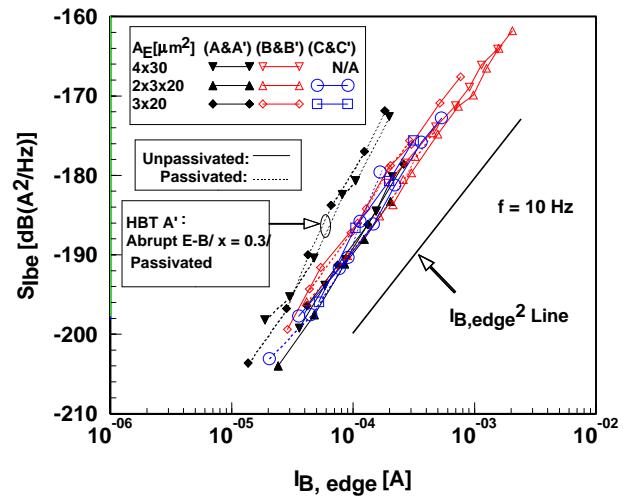


Fig. 3. $S_{Ibe}(10 \text{ Hz})$.vs. total emitter-edge base current ($I_{B, \text{edge}}$) characteristics for HBT's

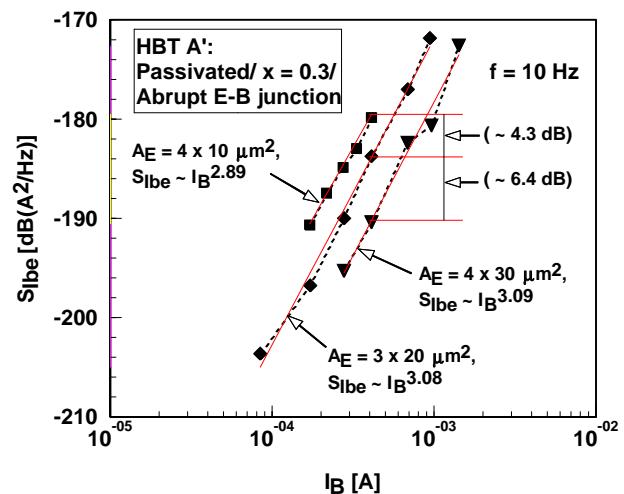


Fig. 4. $S_{Ibe}(10 \text{ Hz})$.vs. base current (I_B) characteristics for HBT A' with different emitter sizes: $4 \times 10 \mu\text{m}^2$, $3 \times 20 \mu\text{m}^2$, and $4 \times 30 \mu\text{m}^2$. $S_{Ibe}(10 \text{ Hz}) \propto I_B^{3.0}$. At the same base current, $S_{Ibe}(10 \text{ Hz}) \propto A_E^{-2.0}$.

uniformly distributed under the emitter, is proportional to $I_B^k A_E^{1-k}$ [7]. To clarify that the $S_{Ibe}(10 \text{ Hz})$ of HBT A' satisfies the aforementioned bulk noise property, Fig. 4 shows the $S_{Ibe}(10 \text{ Hz})$.vs. I_B characteristics for the HBT A' with different emitter sizes. As shown in the figure, $S_{Ibe}(10 \text{ Hz}) \propto I_B^{3.0}$, and $S_{Ibe}(10 \text{ Hz}) \propto A_E^{-2.0}$ for a fixed I_B , clearly suggesting that the HBT A' is in the fundamental bulk noise limit. However, the base current dependency of $S_{Ibe}(10 \text{ Hz}) \propto I_B^{3.0}$ is still unclear. For the comparison purpose, the $S_{Ibe}(10 \text{ Hz})$.vs. J_C

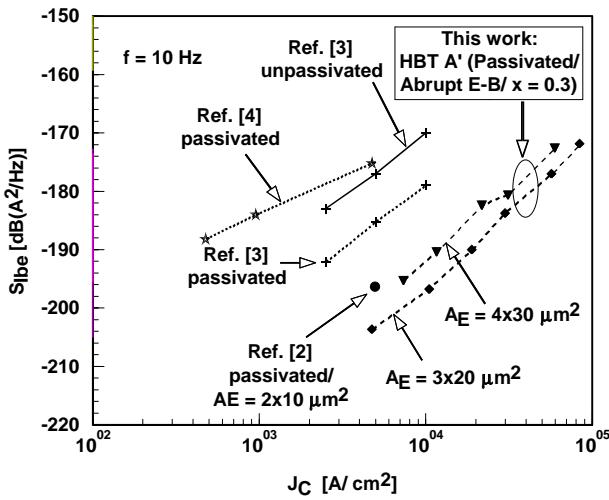


Fig. 5. S_{lbe} (10 Hz) .vs. J_C for HBT A' and other AlGaAs/ GaAs HBT's.

characteristics for our optimized AlGaAs /GaAs HBT's (HBT A') and previously reported AlGaAs/GaAs HBT's are shown in Fig. 5. The noise level of our optimized AlGaAs/GaAs HBT is at least 10 dB lower than that of any other AlGaAs/GaAs HBT's.

CONCLUSION

In conclusion, the surface recombination and its 1/f noise properties of AlGaAs/GaAs HBT's have been investigated as a function of the E-B structure and the surface passivation condition. It is found that the surface recombination 1/f noise can be significantly reduced by the heterojunction launcher of the abrupt E-B junction. By using both the launcher effect and the conventional depleted AlGaAs ledge surface passivation effect, we can greatly suppress the surface recombination currents of HBT's. Consequently, we have achieved a very low 1/f noise corner frequency of 2.8 kHz at the collector current density of 10 kA/cm^2 . This is the lowest 1/f noise corner frequency among the III-V compound semiconductor devices, and as comparable as low-noise Si BJT's. This improved low-frequency noise characteristics of AlGaAs/GaAs HBT will be very helpful in implementing microwave and millimeter-wave low-phase noise oscillators, based on a conventional AlGaAs/GaAs HBT technology.

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