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/cm^2. 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-Ⅴcompound 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	1×10^{19}
	n$^+$ $In_xGa_{1-x}As$ (x:0→0.5)	400	1×10^{19}
	n$^+$ GaAs	500	5×10^{18}
	n GaAs	700	5×10^{17}
Emitter	n $Al_xGa_{1-x}As$ (x:0.3→0)	300	2×10^{17}
	n $Al_{0.3}Ga_{0.7}As$	700	2×10^{17}
Base	p$^+$ GaAs	1000	2×10^{17}
Collector	n GaAs	4000	2×10^{16}
Subcollector	n$^+$ GaAs	6000	5×10^{18}

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

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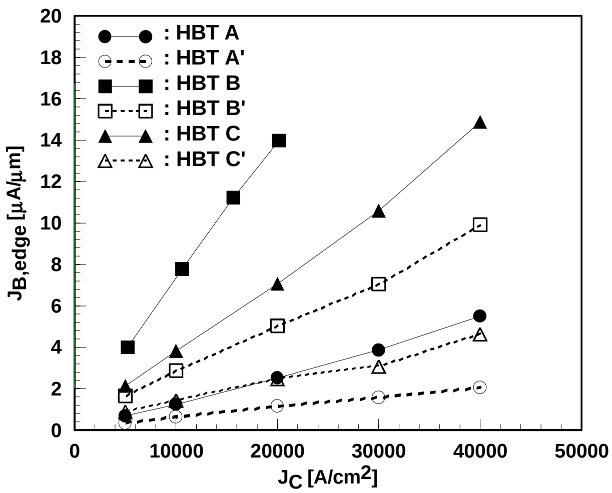

Fig. 1. Edge-emitter base current density ($J_{B,\ edge}$) .vs. collector current density (J_C) characteristics of HBT's

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 ($J_{B,\ edge}$) .vs. collector current density (J_C) characteristics for the various HBT's, confirming our expectation. At J_C = 10 kA/cm^2, the value of $J_{B,\ edge}$ for HBT B is 7.78 µA/µm, which is much larger than 1.24 µA/µm 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], $J_{B,\ edge} = J_C\ s\ W_B\ L_d /\ D_n \propto J_C\ W_B^2$, 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 $J_{B,\ edge}$ 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 $J_{B,\ edge}$ value of 1.24 µA/µm for the unpassivated HBT (HBT A) is, within our knowledge, the lowest value among the unpassivated AlGaAs/GaAs HBT's. At J_C = 10 kA/cm^2, the $J_{B,\ edge}$ 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 $J_C \fallingdotseq 7$ kA/cm^2, and f = 10 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

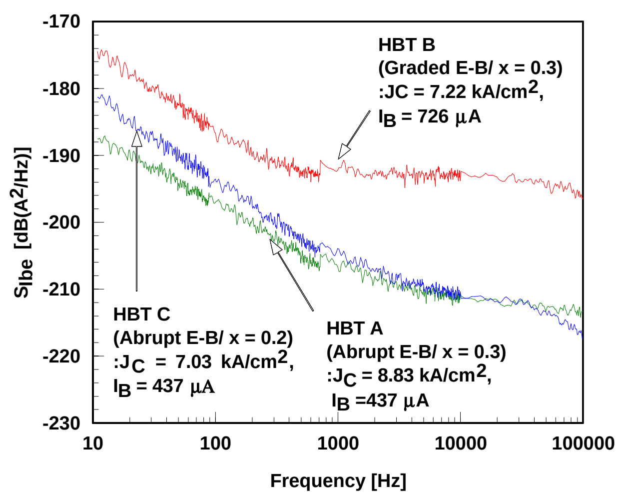

Fig. 2. Low-frequency base current noise (S_{Ibe}) spectra for the unpassivated HBT's with three different E-B structures: HBT A (abrupt E-B/ x = 0.3), HBT B (graded E-B/ x = 0.3), and HBT C (abrupt E-B/ x = 0.2)

Table 3. Corner Frequencies(Fc) At J_C = 10 kA/cm^2

HBT's	HBT A	*HBT A'*	HBT B	HBT B'	HBT C	HBT C'
Fc [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 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 Hz) .vs. $I_{B,\ edge}$ for HBT's with various emitter sizes. Except for HBT A', the values of S_{Ibe}(10 Hz) vary as proportional to only $I_{B,\ edge}^2$, 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 Hz) $\propto$ $I_{B,\ edge}^2$, 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 Hz) is not proportional to $I_{B,\ edge}^2$. 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 ($S_{IB,bulk}$), which is

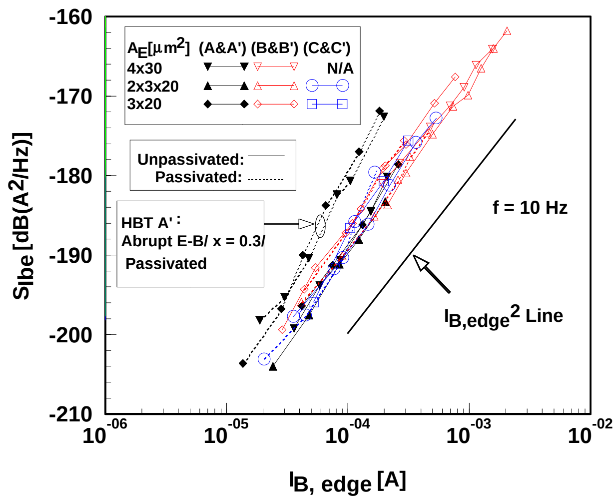

Fig. 3. S_{Ibe}(10 Hz) .vs. total emitter-edge base current ($I_{B,edge}$) characteristics for HBT's

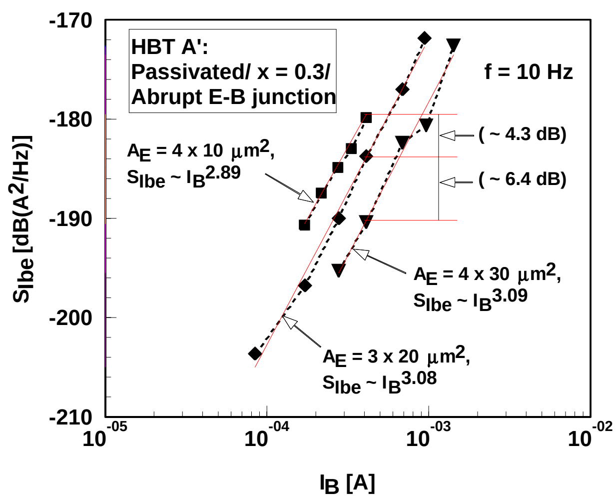

Fig. 4. S_{Ibe} (10 Hz) .vs. base current (I_B) characteristics for HBT A' with different emitter sizes: 4×10 μm^2, 3×20 μm^2 , and 4×30 μm^2. S_{Ibe} (10 Hz) $\propto$ $I_B^{3.0}$. At the same base current, S_{Ibe} (10 Hz) $\propto$ $A_E^{-2.0}$.

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

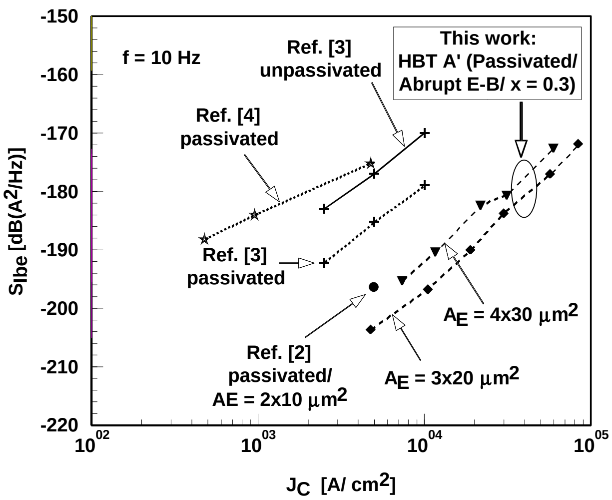

Fig. 5. S_{Ibe} (10 Hz) .vs. J_C for HBT A’ and other AlGaAs/ GaAs HBT’s.

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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ACKNOWLEDGMENT

This work has been partially supported by Korea Agency for Defense Development. Authors thank Mr. H. C. Seo, and Dr. D. S. Ma, Kukje Corporation, for their assistance in ion implantation process. Authors thank Dr. C. T. Kim and Dr. K. W. Chung, LG CIT, for their HBT mask preparation. Constant support and encouragement from Mr. T. Y. Lim and Mr. H. W. Kim, LG CIT, are greatly appreciated.