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Accumulation Mode GaAlAs/GaAs Bipolar Transistor

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The Accumulation Mode Bipolar Transistor is proposed and investigated for the first time. The transistor uses the two dimensional hole gas (2DHG) as an ultra thin base layer, which is accumulated at the AlAs barrier - p^- collector interface. The transistor shows the common-emitter current gain of ~30. The theoretical results reveal that by adopting the p^- collector rather than the n^- collector, and with the higher impurity concentration, the carrier concentration of 2DHG base, the turn-on emitter-base bias, and the punch-through base-collector bias are improved drastically.

1, Introduction

A new type of GaAlAs/GaAs bipolar transistor which uses an accumulated two dimensional hole gas (2DHG) as a base is proposed and investigated. So far, we have developed the GaAs Inversion-Base Bipolar Transistor (GaAs IBT)[1] which uses an inversion layer for the 2DHG base. Though the GaAs IBT has various good features such as the small emitter size effects, the short base transit time, etc., it has some problems to be solved such as the high turn-on bias, the low punch-through bias, etc. In order to overcome those problems, the present device is proposed.

2, Experiments

Figure 1 shows the cross-sectional view of the fully self-aligned Accumulation Mode Bipolar Transistor (Acc BT). The present transistor consists of n^+GaAs emitter ($n^+=5\times10^{18}/cm^3$, 500nm) / undoped GaAlAs graded layer (x=0 → 0.3, 15nm) / undoped AlAs barrier layer (10nm) / p^- GaAs collector ($p^-=2\times10^{16}/cm^3$, 150nm) / n^+ GaAs subcollector ($n^+=5\times10^{18}/cm^3$, 1μm). The emitter length and the width are l_E=10μm, and W_E=1μm, respectively. Although it looks like a HBT with p^- base layer, it operates like an IBT. The impurity concentration and the thickness of p^- collector is low and thin enough for the p^- collector to be completely depleted. By applying the emitter-base bias, the interface between the AlAs barrier and the p^- collector is accumulated and 2DHG which works as a thin base is induced. The difference between the GaAs IBT and the Acc BT is that the GaAs IBT adopts the n^- collector, while the Acc BT p^-collector.

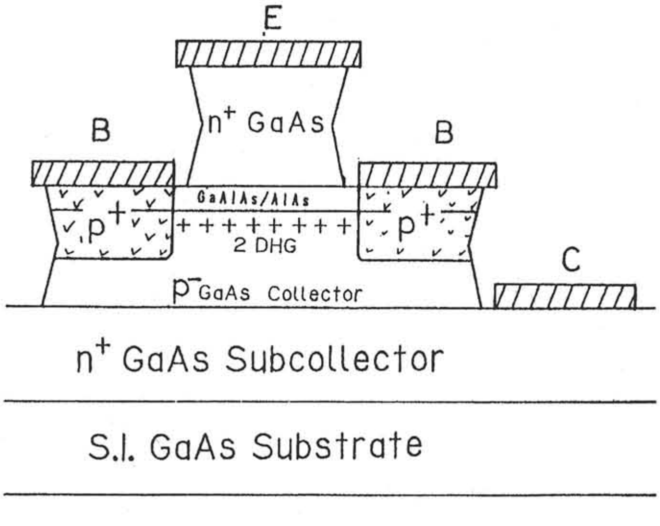

Fig.1, Cross sectional view of Accumulation Mode GaAlAs/GaAs Bipolar Transistor.

Figure 2 shows the common emitter transistor characteristics of (a)IBT and (b)Acc BT, respectively. In both transistors, the current gain of h_{FE}=30 was obtained. The output impedance of the Acc BT at V_{CE}=2V and I_C=0.9mA is 5.5 kohm which is two times higher than that of the IBT (2.6 kohm). This higher output impedance of Acc BT is attributed to the higher 2DHG base carrier concentration as shown in Fig. 5. Therefore the Early effect and the punch through effect are suppressed compared to the case of IBT.

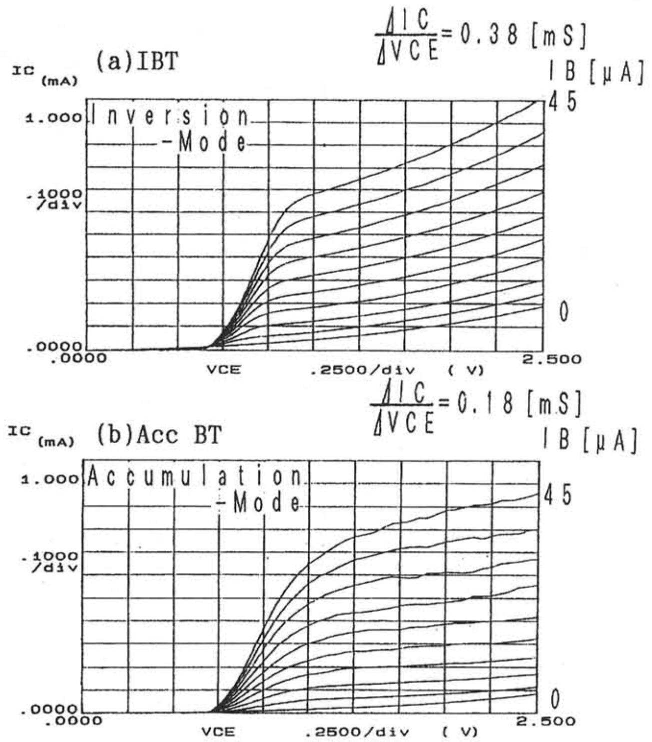

Fig.2, Transistor characteristics of common-emitter mode for (a)IBT and (b)Acc BT.

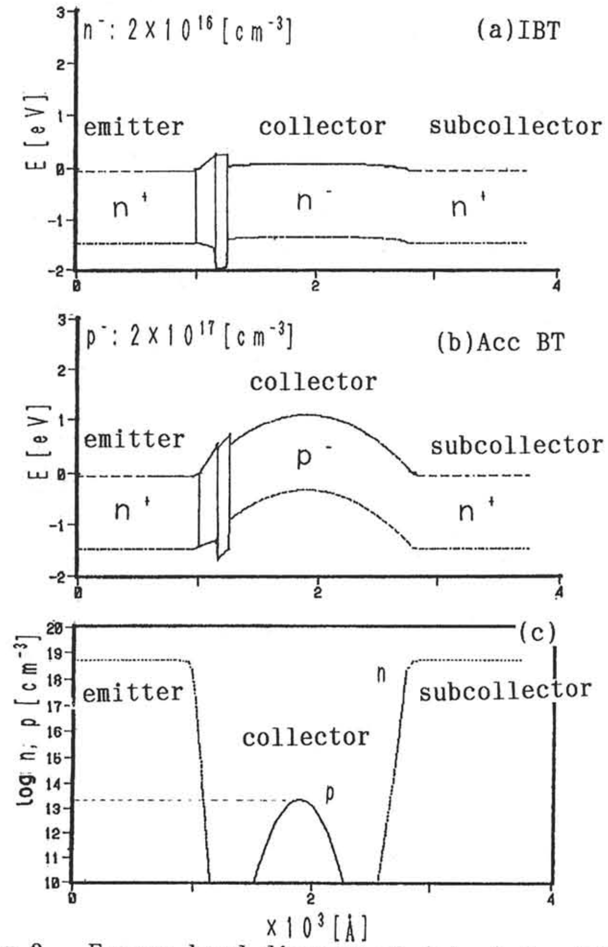

Fig.3, Energy band diagram of (a) GaAs IBT and (b) Acc BT at zero bias condition. (c) Carrier concentration of Acc BT at zero bias condition.

3, Theory

By using the one dimensional simulation, various merits of the Acc BT over the IBT become clear. The device structure which was fabricated was selected for the simulation and the carrier concentration of the collector was varied from $n^-=2x10^{16}/cm^3$ (IBT) to $p^-=2x10^{17}/cm^3$ (Acc BT).

Figure 3 shows the energy band diagram of the (a) IBT (n^- collector), and (b) Acc BT (p^- collector) at zero bias condition. In this figure, the impurity concentration of the p^- collector of the Acc BT was set to the highest value of $p^-=2x10^{17}/cm^3$ to clearly see the effect of the p^- collector. In the IBT, the surface of the n^- collector at AlAs interface is almost in flat-band condition, while in the Acc BT, the surface of the p^- collector at AlAs interface is drawn upward by the built-in potential of p^- collector - n^+ emitter junction. This built-in potential helps to lower the turn-on emitter-base bias as shown in Fig. 5. Figure 3 (c) shows the carrier concentration of the Acc BT at zero bias condition. Though the p^- collector is doped to $2x10^{17}/cm^3$, the peak carrier concentration (holes) is as low as ~ $10^{13}/cm^3$. Therefore, the p^- collector is completely depleted at zero bias condition.

Figure 4 shows the energy band diagram of (a) IBT and (b) Acc BT at the normal operation mode of the transistor when the emitter-base and base-collector bias of

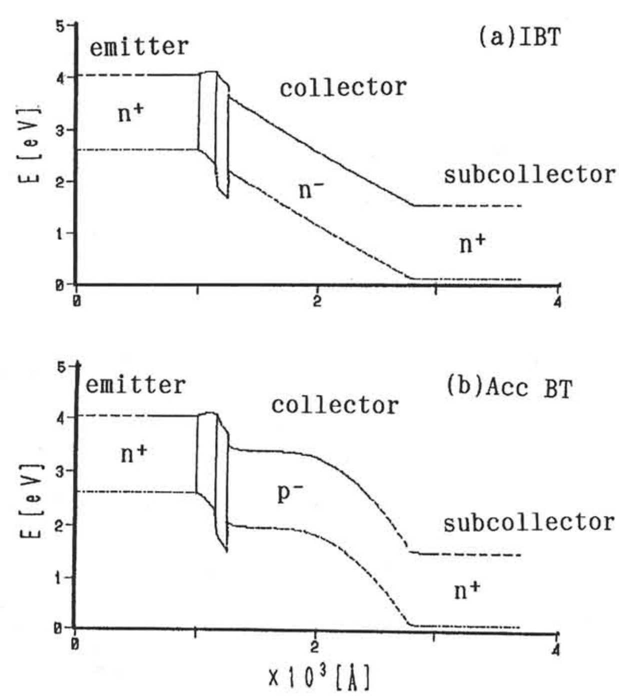

Fig.4, Energy band diagram of (a) IBT and (b) Acc BT when Veb=2.1V and Vbc=-0.4V are applied.

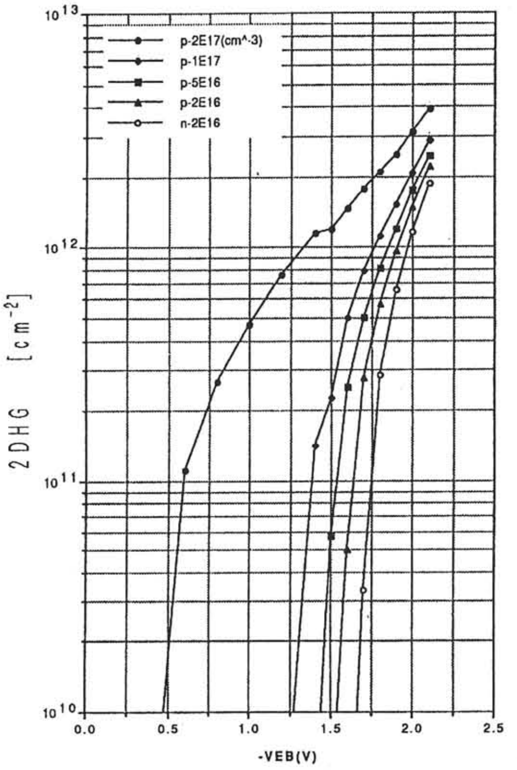

Fig.5, Dependence of carrier concentration of 2DHG on emitter-base bias. Base-collector bias is set to zero volt. Collector is n^- type (IBT) and p^- type (Acc BT).

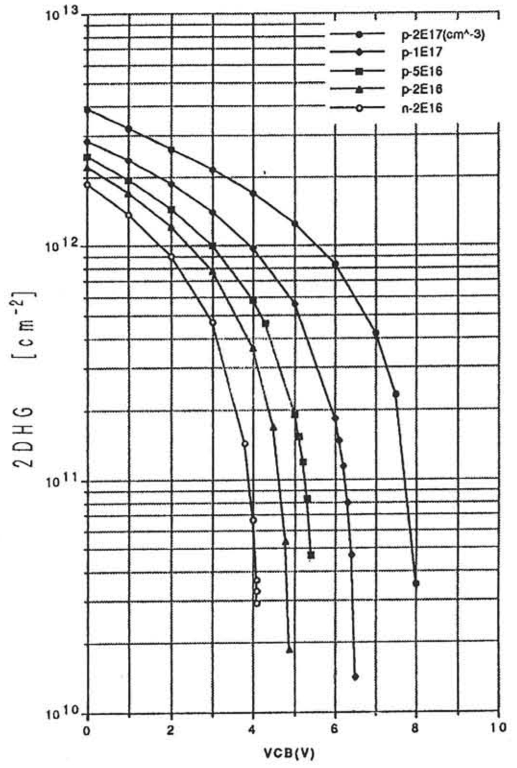

Fig.6, Dependence of carrier concentration of 2DHG on base-collector bias. Emitter-base bias is set to V_{eb}=2.1V. Collector is n^- type (IBT) and p^- type (Acc BT).

V_{eb}=2.1V, V_{bc}=-0.4V are applied. In the energy band of the IBT, the n^- collector shows the steep slope, while in the Acc BT, the p^- collector has the mild slope, and at the dip between AlAs barrier and the p^- collector, the two dimensional hole is accumulated which works as a thin base.

Figure 5 shows the dependence of the carrier concentration of 2DHG base on the emitter-base bias. The base-collector bias is set to zero volt. The collector type is n or p and the impurity concentration is used as a parameter. By adopting the p^- collector rather than n^- collector, and with the higher impurity concentration, the turn-on emitter-base bias which needs to induce the 2DHG (>$3x10^{10}/cm^2$) decreased drastically from ~ 1.7V to ~ 0.5V. This is because, the higher the impurity concentration of the p^- collector, the built-in potential of the p^- collector - n^+ emitter junction becomes higher (see Fig. 3(b)). Therefore, the surface of the p^- collector at the AlAs interface is drawn upward higher and the lower emitter-base bias can induce the 2DHG, and that makes the emitter-base turn-on bias smaller. Furthermore, the base carrier concentration at V_{eb}=2.1V increased more than 2 times from ~ $2x10^{12}/cm^2$ to ~ $4x10^{12}/cm^2$.

Similarly, the punch-through base-collector bias which makes the 2DHG base vanished (<$3x10^{10}/cm^2$) is improved from ~4V to ~8V by adopting the p^- collector rather than n^- collector and with the higher impurity concentration as shown in Fig 6. The main reason of the improved punch-through bias is that the higher the impurity concentration, the 2DHG concentration becomes higher (see Fig. 5), therefore the punch-through bias becomes larger.

4. Conclusion

Accumulation Mode Bipolar Transistor is proposed and investigated for the first time. The experimental and theoretical results show that by adopting the p^- collector rather than n^- collector, the output conductance is improved more than two times, the emitter-base turn-on bias becomes smaller from ~1.7V to ~0.5V, and the punch-through bias is improved from 4V to 8V. Thus the Accumulation Mode Bipolar Transistor overcomes the problems of the GaAs IBT with retaining all the features of the IBT.

Reference

1) K.Matsumoto, et al., IEEE Electron Device Lett. Vol.7,p.627,1986