Low Turn-on Voltage InGaP/GaAsSb/GaAs DHBT Grown by MOCVD

C.H. Huang, Y.C. Chin, M.N. Jseng, C.H. Lin and Michael.H.T. Yang
Visual Photonics Epitaxy Co. Ltd., No. 16, Kung Yeh 1st Road, Ping-Jen City, 324 Taoyuan, Taiwan, R.O.C.
Tel:886-3-4192969,Fax:886-3-4192968,E-mail:James@VPEC.com.tw

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ABSTRACT

In this work, an InGaP/GaAsSb/GaAs DHBT with carbon doping up to 4E19/cm^3 GaAsSb base was studied. A current gain of 115 at the collector current density of 25KA/cm2 was achieved for the Rbs of about 530ohm/sq. Over 100mV turn-on voltage and knee voltage reduction and 2/3 offset voltage were obtained for the GaAsSb based HBT compared with the standard InGaP/GaAs SHBT. The DC gain of the device is less temperature dependence (the DC gain variation is less than 3% for the temperature range from 25 degree C to 100 degree C.) due to the larger valence band discontinuity between InGaP emitter and GaAsSb base, compare with the standard InGaP/GaAs SHBT. These results indicate that GaAsSb is a great choice for the base material of a low turn-on voltage HBT.

INTRODUCTION

GaAs HBT has demonstrated excellent performance for power amplifier (PA) in handset and WLAN applications [1-4]. For the next generation of PAs, low power consumption and high efficiency are required for longer battery life. To meet these requirements, the low turn-on voltage HBT is needed. One way to reduce the turn-on voltage of HBT device is to lower the band gap of the base material. Several lower band gap material systems have been investigated for the base of HBT. One of them was GaInNAs [5]. However, The large conduction band discontinuity in type I band alignment of GaInNAs/GaAs material system would be easy to cause the collector current blocking effect at B/C junction at high current density. The current blocking effect would degrade the performance of the device and complicate the B/C structure design for preventing this effect. Besides, the control of the small composition of nitrogen would also be a challenge of future production. Another choice of lower band gap material for the base is GaAsSb [6-8]. In the GaAsSb/GaAs material system, the band alignment is type II [9,10]. The type II band alignment at B/C junction would naturally eliminate the collector blocking effect without a complicated design of the B/C junction structure.

Device Structure and Fabrication Process

The basic MOCVD grown epitaxial structure of InGaP/GaAsSb/GaAs DHBT including 700nm (n=1.2E16/cm^3) GaAs collector, GaAsSb base and 40nm (n=4E17/cm^3) InGaP emitter. Three GaAsSb based HBT devices with various Sb composition and base thickness were grown. They are 50nm thick $GaAs_{0.95}Sb_{0.05}$, 50nm thick $GaAs_{0.93}Sb_{0.07}$ and 30nm thick $GaAs_{0.91}Sb_{0.09}$ respectively. The carbon doping concentration for the GaAsSb base layers were all kept at 4E19/cm3. One standard InGaP/GaAs SHBT was grown for comparison, the layer structure of the InGaP/GaAs HBT including 700nm (n=1.2E16/cm3) GaAs collector, 80nm (p=4E19/cm3) GaAs base and 40nm (n=4E17/cm3) InGaP emitter.

The InGaP/GaAsSb/GaAs DHBT device was fabricated by conventional photo lithography and selective chemical etching which was exactly the same as the fabrication process of those InGaP/GaAs HBT device

DEVICE CHARACTERIZATION AND DISCUSSION

Figure 1 shows the Gummel plots of $GaAs_{0.93}Sb_{0.07}$ base HBT and standard InGaP/GaAs HBT. The E/B junction area of these devices is 15x15um^2. For the $GaAs_{0.93}Sb_{0.07}$ base HBT, the Rbs is 530ohm/sq. and the DC gain is about 115 at collector current density of 25kA/cm^2, for the standard InGaP/GaAs HBT, the Rbs is 200ohm/sq. and the DC gain is about 110 at collector current density of 25kA/cm^2. Because of the lower base band gap energy of $GaAs_{0.93}Sb_{0.07}$ base which is about 1.32eV. The E/B junction turn-on voltage Vbe of the $GaAs_{0.93}Sb_{0.07}$ base HBT is 100mV lower than standard InGaP/GaAs HBT.

Compared the collector current ideality factor of GaAsSb base HBT and the standard InGaP/GaAs HBT that are all about 1.03. The small and identical collector current ideality factor for GaAsSb based HBT and GaAs base HBT is due to the very small E/B junction potential spike in these two devices. In the low bias region of this Gummel polts, the base current ideality factor of InGaP/GaAsSb HBT is much smaller than that of the InGaP/GaAs HBT. The larger difference is due to the better junction quality of InGaP/GaAsSb E/B junction with lower space charge recombination current.

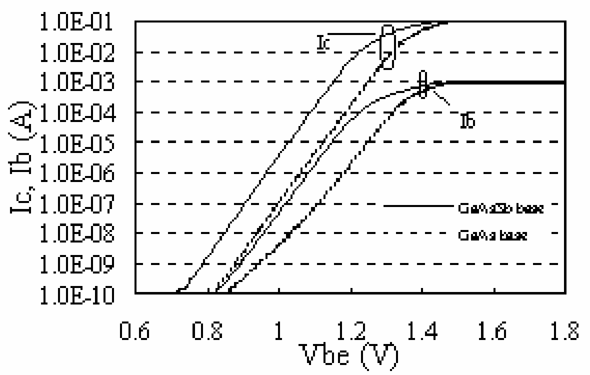

Figure 1. Small area device (15umx15um) Gummel plots of an InGaP/ $GaAs_{0.93}Sb_{0.07}$ DHBT and an InGaP/GaAs HBT.

Figure 2 sumarized the common emitter I-V curves of $GaAs_{0.93}Sb_{0.07}$ base HBT and standard InGaP/GaAs HBTs, the step of base current were 130uA and 120uA, respectively. The E/B junction areas of these devices are 15x15um^2. In this GaAsSb base HBT. There is no current blocking effect appears in the saturation region up to current density of 35kA/cm^2 that support the band alignment of GaAsSb base and GaAs collector is type II band alignment. Comparing the offset voltage and knee voltage in these two devices. There is over 100mV knee voltage reduction for $GaAs_{0.93}Sb_{0.07}$ base HBT thanks to the DHBT structure and type II band alignment at B/C junction. The offset voltages of 73 mV for the $GaAs_{0.93}Sb_{0.07}$ based HBT is also lower than 113 mV for the standard InGaP/GaAs HBTs. In the linear region of the common emitter I-V curves. The heating effect of the $GaAs_{0.92}Sb_{0.08}$ base HBT is much less than standard InGaP/GaAs HBT. This is due to the larger valence band discontinuity between InGaP emitter and GaAsSb base. The higher hole barrier actually prevents the holes back injecting from base to emitter during the junction heating in higher power operation.

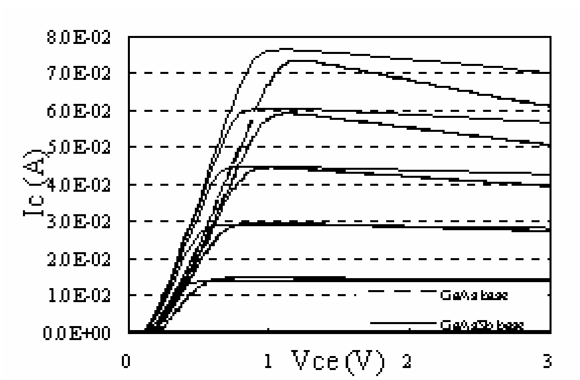

Figure 2. Common emitter I-V curves of a small area device (15umx15um) InGaP/ $GaAs_{0.93}Sb_{0.07}$ DHBT and an InGaP/GaAs HBT.

To further study the B/C junction band alignment between GaAsSb base and GaAs collector. The common base I-V curves of $GaAs_{0.93}Sb_{0.07}$ base HBT and standard InGaP/GaAs HBTs with E/B junction area of 15x15um^2 were shown in Figure 3. In this common base I-V curves, the B/C junction turn-on voltage of GaAsSb based HBT is lower than that of the GaAs based HBT, thanks to the lower band gap energy in GaAsSb base. In the saturation region of GaAsSb based HBT, there is no current blocking effect appears and the I-V curves is the same as that of the standard InGaP/GaAs SHBT with B/C homojunction at collector current density up to 44kA/cm^2 which is the highest current density that our device can be measured. This evidence support that the band alignment of GaAsSb base and GaAs collector is type II.

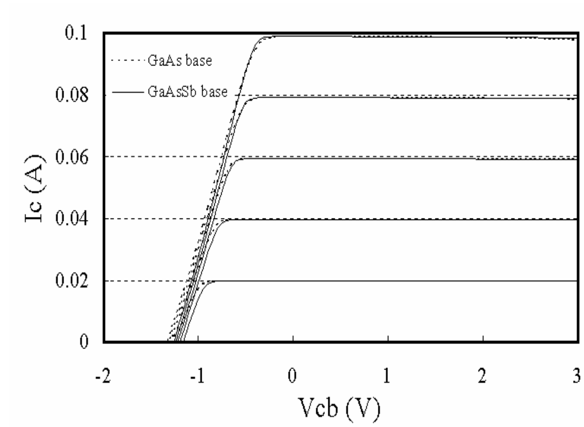

Figure 3. Common base I-V curves of a small area device (15umx15um) InGaP/$GaAs_{0.93}Sb_{0.07}$ DHBT and an InGaP/GaAs HBT, the step of emitter current were 20mA.

Figure 4 shows the temperature dependent DC current gain of $GaAs_{0.93}Sb_{0.07}$ base HBT. The DC gain was measured at current density of 1.8kA/cm^2 and was normalized to the DC gain measured at room temperature. Since the larger valence band discontinuity between InGaP emitter and GaAsSb base forms higher hole barrier to keep holes in the base from being back injected to emitter at higher temperature operation, the variation of DC current gain with temperature is very small which is less than 3% DC current gain drop for the measurement temperature from room temperature up to 100 degree C.

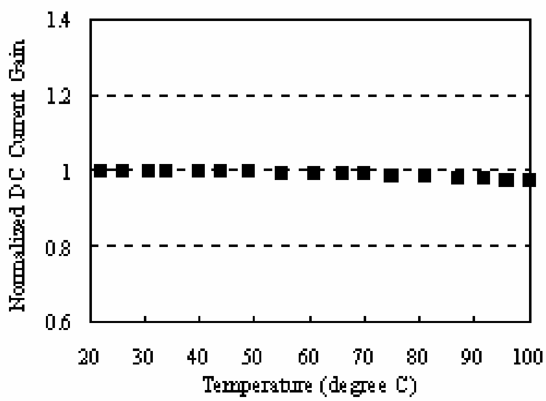

Figure 4. Normalized DC current gain versus temperature of an InGaP/ $GaAs_{0.93}Sb_{0.07}$ DHBT.

Figure 5 shows the Gummel plots of another two GaAsSb base HBT devices with base Sb composition of 0.05 and 0.09, respectively. The Gummel polt of standard InGaP/GaAs HBT was also included in this figure for comparison. The E/B junction area of these devices is 15x15um^2. In this Gummel plot both of the GaAsSb base HBTs all show lower base current ideality factor in low bias region. The Rbs of $GaAs_{0.95}Sb_{0.05}$ base HBT is 420ohm/sq. and the DC gain is about 112 at collector current density of 25kA/cm^2. In the $GaAs_{0.95}Sb_{0.05}$ based HBT, the Sb composition in the base is lower, hence the base band gap enengy reduction is less than that of the $GaAs_{0.93}Sb_{0.07}$ based HBT, therefore the Vbe reduction is only about 70mV. However, with the lower Sb composition in the base, the hole mobility of $GaAs_{0.95}Sb_{0.05}$ base is higher than that of the $GaAs_{0.93}Sb_{0.07}$ base and thus Rbs is lower. The DC gain to Rbs ratio of the $GaAs_{0.95}Sb_{0.05}$ based HBT is also higher than that of the $GaAs_{0.93}Sb_{0.07}$ based HBT, the reason is still not clear. For the $GaAs_{0.91}Sb_{0.09}$ base HBT, the Rbs is 1000ohm/sq. and the DC gain is about 120 at collector current density of 25kA/cm^2. Since there is additional base band gap energy reduction for the $GaAs_{0.91}Sb_{0.09}$ base HBT, the Vbe of this $GaAs_{0.91}Sb_{0.09}$ based HBT is about 150mV lower than that of the GaAs based HBT.

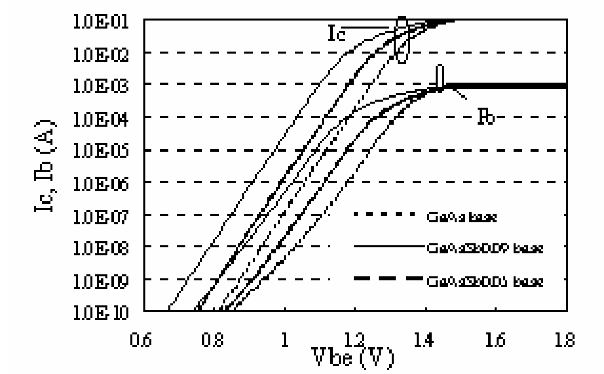

Figure 5. Small area device (15umx15um) Gummel plots of an InGaP/ $GaAs_{0.95}Sb_{0.05}$ DHBT, an InGaP/ $GaAs_{0.91}Sb_{0.09}$ DHBT and an InGaP/GaAs HBT.

CONCLUSIONS

High performanced low turn-on voltage and knee voltage of InGaP/GaAsSb HBT has been demonstrated. Turn-on voltage (Vbe) reduction of as high as 150mV has been achieved by increasing the Sb composition in base. The InGaP/GaAsSb E/B junction quality is the same or even better than that of standard InGaP/GaAs HBT. Due to the larger valence band discontinuity between InGaP emitter and GaAsSb base, the DC gain of InGaP/GaAsSb HBT device is less temperature dependence. The DC gain variation is less than 3% for the temperature range from 25 degree C to 100 degree C. These results indicated that GaAsSb is a great choice for the base material of a low turn-on voltage HBT.

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ACRONYMS

DHBT: Double Heterojunction Bipolar Transistor
SHBT: Single Heterojunction Bipolar Transistor