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InGaP/GaAsSb/GaAs DHBTs with Low Turn-on Voltage and High Current Gain

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Abstract

An InGaP/GaAsSb/GaAs double heterojunction bipolar transistor (DHBT) is presented. It features the use of a fully strained pseudomorphic GaAsSb (Sb composition: 10.4%) as the base layer and an InGaP layer as the emitter, which both eliminates the misfit dislocations and increases the valence band discontinuity at the InGaP/GaAsSb interface. A current gain of 200 has been obtained from the InGaP/GaAsSb/GaAs DHBT, which is the highest value obtained from GaAsSb base GaAs-based HBTs. The turn-on voltage of the device is typically 0.914 V for the 10.4% Sb composition, which is 0.176V lower than that of traditional InGaP/GaAs HBT. The results show that GaAsSb is a suitable base material for reducing the turn-on voltage of GaAs HBTs.

I. Introduction

One of the major trends for future high-performance mobile handsets is to realize low-power operation so as to reduce the power dissipation and extend the talk-time before recharging of the battery. In order to meet the requirements of low-power operation, several different HBT material systems have been investigated. One of the attractive material systems is InGaAsN base HBT [1-3]. By incorporating a proper amount of nitrogen and indium into GaAs, GaInAsN lattice-matched to GaAs can be obtained with a significant energy band-gap reduction. However, because of the large conduction band discontinuity between InGaAsN base and GaAs collector, a collector current blocking effect would occur, giving rise to a drastic degradation of current gain at a high collector current density. Although by the insertion of graded layers between the base and collector junction, the current blocking effect can be suppressed, this complicates the transistor design and fabrication.

Another effort is to use GaAsSb as the narrow band gap material for the base layer of GaAs HBTs. In comparison with a lattice-matched GaAs base, the smaller band gap of GaAsSb can reduce the turn-on voltage, thus the power dissipation in circuits. Moreover, the band lineup at the GaAsSb/GaAs interface is staggered ("type II") lineup [4], which would eliminate any collector current blocking. GaAs-based HBTs with GaAsSb base layers have been already reported [5-8], but only limited information was given. In the previous work, the grown emitter-base junction was either an AlGaAs/GaAsSb [5-7] or a GaAs/GaAsSb heterojunction [8], and the devices showed poor dc current gain and large recombination current. It was attributed to the large surface recombination at GaAs surface and depletion region. Recently, our group implemented a novel InGaP/GaAsSb/GaAs DHBT, which has an improved current gain and a low turn-on voltage [9]. In this work we increase Sb composition to 10.4% in pseudomorphic GaAsSb base to further reduce the turn-on voltage. At the same time, InGaP is still used instead of GaAs as the emitter to increase the valence band discontinuity at the emitter-base heterojunction. Thus, we have implemented the InGaP/GaAsSb/GaAs DHBT with a lower turn-on voltage and a higher current gain.

II. Material Growth and Device Fabrication

InGaP/GaAsSb/GaAs DHBT structure was grown on a semi-insulating (100) GaAs substrate by MOCVD. TMGa, TMIn, TMSb, TBP, and TBA were used as the organometallic sources. Carbon and silicon were used as p- and n-type dopants, respectively. The device structure consists of a 500 nm n>3×10^{18} cm^{-3}
GaAs sub-collector, a 500 nm n=5×10^{16} \text{cm}^{-3} \text{GaAs}
collector, a 30 nm p=8×10^{15} \text{cm}^{-3} \text{GaAsSb}
base (Sb composition: 10.4 \%), a 50 nm n=3×10^{17} \text{cm}^{-3} \text{InGaP}
emitter, a 150 nm n=4×10^{18} \text{cm}^{-3} \text{GaAs}
layer, a 50 nm 
\text{p=1×10^{19}} \text{cm}^{-3} \text{compositionally}
graded In_{x}\text{GaAs}_{1-x} \text{cap}
layer (x=0.05), and a 50 nm n=1×10^{19} \text{cm}^{-3}
\text{In}_{0.5}\text{Ga}_{0.5} \text{Sb}
cap ohmic contact layer. The Sb
composition was confirmed by high-resolution x-ray
diffraction measurement. The surface morphology was
observed by atomic force microscope (AFM) and no
crosshatched patterns associated with misfit
dislocations were observed. This suggests that the
GaAsSb base layer is fully strained. The structure was
fabricated into devices using optical lithography and
chemical wet selective etching for mesa definition.

uniform current gain under the small current level.
The dc current gain reaches 100 even at the base
current level of 1 \mu A. Measured current gain is much
higher than previously reported for GaAs/GaAsSb
DHBTs [5][7]. The improvement of the current gain is
attributed to the use of a fully strained pseudomorphic
GaAsSb layer, which effectively eliminates the misfit
dislocation. Another cause is due to the use of InGaP
as the emitter layer, which has a low surface
recombination velocity. Measured emitter-collector
offset voltage is about 200 mV and the breakdown
voltage of emitter-collector BV_{ceo} is 6-7 V.

III. Device Performance and Discussion

The dc performances of the devices were measured
using a HP4155 semiconductor parameter analyzer.
The devices were biased in the common emitter
configuration. Figure 1 shows the dependence of the
collector current density J_{c} on the emitter-base voltage
V_{BE} of an InGaP/GaAsSb/GaAs DHBT and an
InGaP/GaAs HBT with an emitter size of 100x100
\mu m^{2}. It can be seen that the turn-on voltage of the
conventional InGaP/GaAs HBT at J_{c}=1A/cm^{2} is 1.09
V and the turn-on voltage of InGaP/GaAsSb/GaAs
DHBT is 0.914 V. The turn-on voltage of
InGaP/GaAsSb/GaAs DHBT is 0.176 V lower than
that of conventional InGaP/GaAs HBT, indicating that
GaAsSb is a suitable material for reducing the turn-on
voltage of GaAs-based HBTs.

Large area InGaP/GaAsSb/GaAs DHBTs
(100x100 \mu m^{2}) were fabricated on the three layers to
assess the epitaxial material quality. Figure 2 shows
the common-emitter I-V characteristics of the
InGaP/GaAsSb/GaAs DHBT. The device displays

Fig. 1: The dependence of collector current density on
emitter-base voltage V_{BE} of an InGaP/GaAsSb/GaAs
DHBT and an conventional InGaP/GaAs HBT

Fig. 2: Common-emitter I-V characteristics for a
large area (100x100 \mu m^{2}) InGaP/GaAsSb/GaAs
DHBT under (a) small current (b) large current

Figure 3 shows the dependence of current gain on the
collector current. As shown in Fig. 3, when the
collector current increases from 0.1 mA to 50 mA, the
incremental current gain H_{fe} gain continues to
increase. This observation indicates that the base-
emitter space charge recombination current is the
main base current component [10]. It is
understandable, because the base doping is only
8×10^{18} /cm^{3} in this work. A maximum current gain H_{fe}
of 200 has been obtained at a collector current of 50 mA around.

Figure 4 shows a representative Gummel plot for the large area InGaP/GaAsSb/GaAs DHBT. The ideality factor of the collector current is 1.01. The base current is significantly divided into two parts. When Vbe<0.8 V, the ideality factor of the base current is more than 2.0 and the dominant recombination is the EB junction space charge recombination. When Vbe>0.8 V, the ideality factor of the base current is 1.47, indicating that both the space charge and the base bulk recombination simultaneously make difference. In comparison with GaAs/GaAsSb/GaAs DHBT [8], the base recombination current of InGaP/GaAsSb/GaAs DHBT is greatly reduced due to the use of InGaP as emitter layer. In addition to the improvement of the current gain, the use of InGaP emitter layer is also beneficial to the improvement of device reliability [11]. This work indicates that InGaP/GaAsSb/GaAs DHBT grown by MOCVD in present study is better than GaAs/GaAsSb/GaAs DHBT and can be a better candidate for the low turn-on voltage device.

IV. Conclusion

In summary, we have demonstrated the low turn on voltage InGaP/GaAsSb/GaAs DHBT, which exhibits excellent DC performances. The device shows a low turn-on voltage, which is 0.17-0.19 V lower than that of conventional InGaP/GaAs HBTs. These results show that GaAsSb is a suitable base material for reducing the turn-on voltage of GaAs HBTs. Our results also reveal that InGaP/GaAsSb/GaAs DHBT grown by MOCVD is
better than reported GaAs/GaAsSb/GaAs DHBT. Work is under way to optimize material properties to improve further the DC performance and RF performances.

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