6-inch MOVPE Metamorphic HBT with Low Indium Composition InGaAs base and collector for High Power Application

Y. Otoki, T. Tsuji, N. Sato, T. Tanaka, H. Kamogawa, and Y. Sasaki

Hitachi Cable Ltd., Takasago Works, 880 Isagozawa, Hitachi 319-1418, Japan
phone: +81-294-42-5098, email: otoki.yohei@hitachi-cable.co.jp

Abstract

M-HBT epiwafers with low indium composition $In_xGa_{1-x}As$ (x=0.05, 0.10, 0.15) collector and base layer were grown metamorphically on GaAs substrate by MOVPE method. The M-HBT device with 75×75μm emitter area showed reduced turn-on voltage from 1.091 V in conventional InGaP-HBT to 1.063, 0.994 and 0.903 V respectively along with the reduction in base layer band gap. Resistance in sub collector was reduced because of high electron mobility in InGaAs. On the other hand, breakdown voltages have been kept at almost the same value with GaAs base layer.

INTRODUCTION

InGaP/GaAs heterojunction bipolar transistors have been widely accepted as high performance microwave devices. High frequency power amplifiers in digital cellular phones and high-speed integrated circuits in optic-fiber communication transceivers are typical applications of InGaP-HBT. In conventional InGaP-HBT, GaAs is used as base layer. The band gap of GaAs is relatively large (1.42 eV), and this large band gap causes high turn-on voltage and increases the power dissipation of HBT circuits. The microwave devices in the next generation will require higher efficiency and higher linearity as well as lower costs. High efficiency will be achieved by reducing turn-on voltage and the series resistance in the HBTs. Although InP-HBT with InGaAs or GaAsSb base layer is known to have low turn-on voltage, its production costs would be unacceptably high due to InP substrates' high pricing and difficulties in handling. The use of GaInNAs or GaAsSb as base layer in GaAs-HBT, which enables us to make use of the matured GaAs manufacturing technology [1][2], could be a reasonable way to improve the efficiency without cost increase. Our solution, however, is to apply metamorphic epi-growth technique to reduce band gap of base layer material in HBT. We have already reported the feasibility of metamorphic HEMT epitaxial growth on GaAs using MOVPE [3][4], and we applied this technology into the production of M-HBT epiwafers with lattice-mismatched InGaAs base and collector layer on GaAs substrate. M-HBT devices, which have already reported in [5], has 53% indium composition and lattice matched to InP. However, it is concerned that the 53% indium composition M-HBT could have high dislocation density because of the large lattice misfit. The breakdown voltage is low in 53% M-HBT, thus it is not favorable for high power amplifiers. In this work, we report the realization of the low turn-on voltage M-HBT with low indium composition (5-15%) that doesn't affect breakdown voltage nor cause high-density dislocation. Reduction of collector resistance is also discussed.

EXPERIMENTAL

The samples were grown by low-pressure metal organic vapor phase epitaxy (MOVPE) method. The MOVPE reactor is facedown type with multi-wafer (5×6") handling capability. CBr_4 was chosen as precursor for p-type carbon doping in

50nm Se-doped $In_{0.7}GaAs$ (2E19cm^{-3})
50nm Se-doped graded $In_{x\to0.7}GaAs$ (2E19cm^{-3})
100nm Si-doped In_xGaAs (3E18cm^{-3})
50nm Si-doped In_yGaP (3E17cm^{-3})
80nm C-doped In_xGaAs (4E19cm^{-3})
700nm Si-doped In_xGaAs (2E16cm^{-3})
500nm Si-doped In_xGaAs (3E18cm^{-3})
300nm undoped graded $In_{0\to x}GaAs$ (M buffer)
S.I. GaAs substrate

Fig. 1. Illustration of epi structure in HBTs. For conventional InGaP-HBT, x value in InGaAs layer is zero. For M-HBT, x values are 0.05, 0.10 and 0.15. Indium composition in InGaP emitter (y) is also raised so that it can lattice match to InGaAs base and collector.

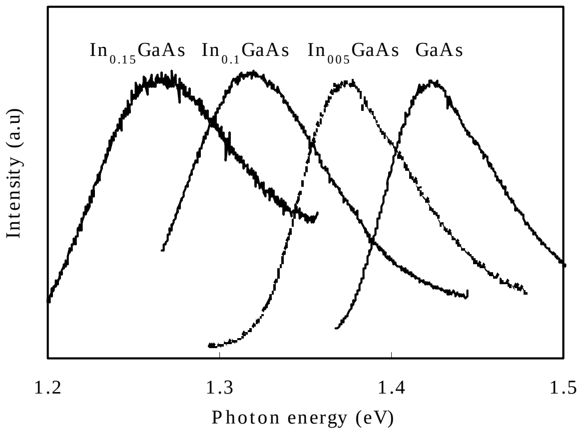


Fig. 2. Photo luminescence spectrum of GaAs and In_xGaAs (x=0.05, 0.1, 0.15) subcollector layer.

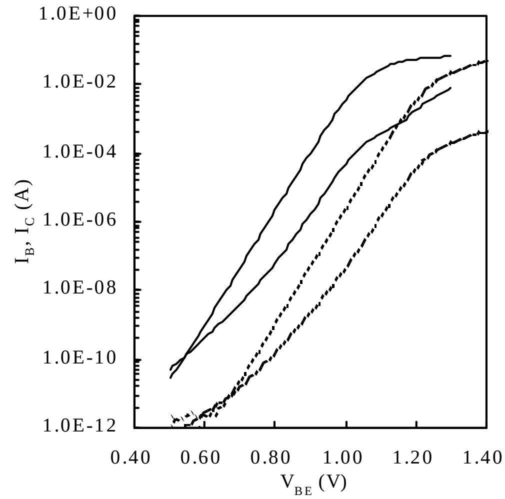


Fig. 3. Gummel plot for M-HBT with $In_xGa_{1-x}As$ base layer (x=0.15) base layer and conventional InGaP-HBT with GaAs base layer. Large emitter area devices 75×75µm) were used for the D. C. testing.

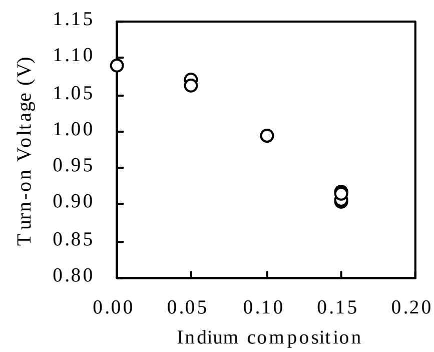
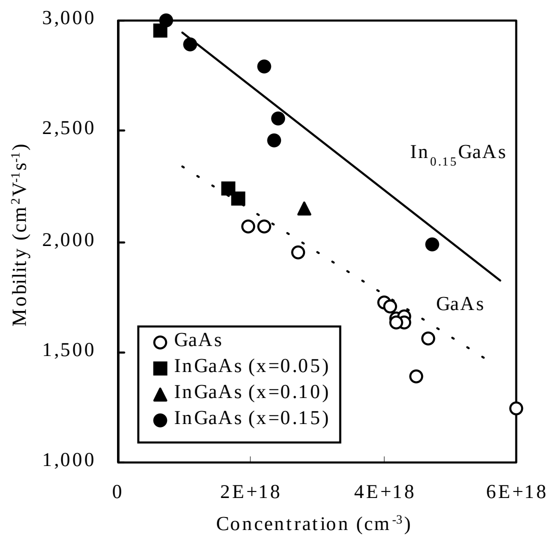


Fig. 4. Turn-on voltages in M-HBT as a function of indium composition (x) in $In_xGa_{1-x}As$ base layer. V_{BE} at 2A/cm2 collector current in 75×75µm emitter area is defined as the turn-on voltage in this case.

base layer. Silicon was used as n-type dopant in subcollector, collector and emitter layer, and selenium was used for emitter non-alloy contact layer. Figure 1 shows the epi structure used in this study. Linear graded InGaAs buffer layer was grown metamorphically to relieve the strain caused by the misfit between GaAs substate and InGaAs collector. The roughness of the layer (RMS) characterized by AFM was less than 3nm. Lattice constant of InGaP emitter was controlled so that it could lattice match to the InGaAs base layer. Indium composition in metamorphic buffer, collector and base layer was characterized using photoluminescence (PL) measurements, which performed at room temperature with Ar^+ laser excitation. Figure 2 shows PL spectra of GaAs and $In_xGa_{1-x}As$ (x=0.05, 0.1, 0.15) subcollector layer before depositing base, emitter and cap layer. The band gap reduces with increasing indium composition as shown the figure. Large area devices were fabricated by non-selfalign process. Ni/Au system was used for emitter, base, and collector metalization. Emitter area size is 75×75µm for D.C. testing and 150×150µm for breakdown voltage characterization. Agilent 4155C parameter analyzer was used for D.C. measurement.

RESULTS AND DISCUSSION

Gummel plots of collector and base current for conventional InGaP-HBT with GaAs base layer and M-HBT with $In_xGa_{1-x}As$ base layer (x=0.15) were shown in figure 3. Collector ideality factors in M-HBT are almost unity and the same with those in InGaP-HBT, indicating that collector current is limited by the carrier transport in base layer, not by the conduction band barrier transport which is usually observed in $InP/In_{0.53}GaAs$ heterojunction bipolar transistor. The reason for this is that indium composition in this work is low and thus the conduction band spike at InGaP/InGaAs hetero interface is small enough for carrier to be smoothly transported from emitter to collector. It should be noticed that I_C in M-HBT shifted to low V_{BE} region, implying the reduction of turn-on voltage. However, I_B crossed I_C at little higher collector current in M-HBT, probably because of the base leak current related to the dislocation in metamorphic buffer layer. It will be improved by optimizing the buffer structure soon. Figure 4 shows the turn-on voltages, which is defined as V_{BE} value to obtain 2 A/cm^2 collector current in



75×75μm emitter device, as a function of indium

Fig. 5. Relation between carrier concentration and carrier mobility in n-GaAs and n-InGaAs, which are subcollector material in InGaP-HBT and M-HBT, respectively.

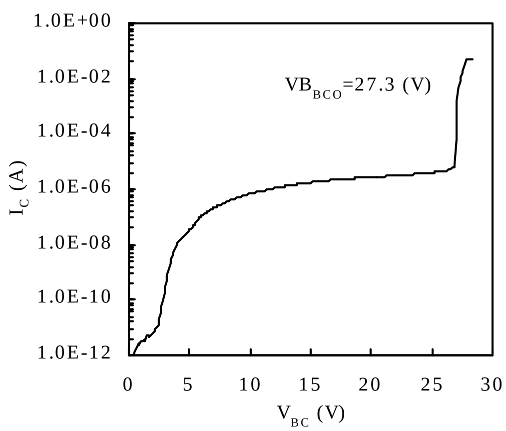
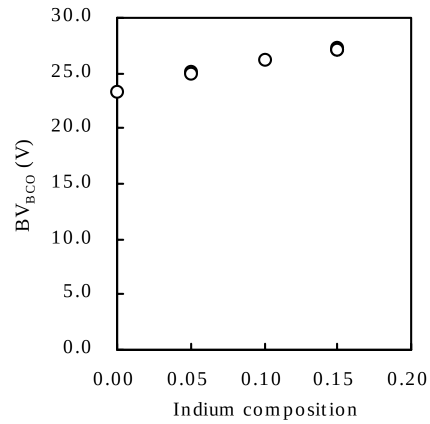


Fig. 6. Measured collector current as function of base/collector voltage for breakdown voltage testing of M-HBT ($In_{0.15}GaAs$).

composition in base layer. Compared to the 1.091 (V) in InGaP-HBT, the turn-on voltage in M-HBT is reduced to 1.063, 0.994 and 0.903 (V) respectively, in proportion to its indium composition. Reduction of the turn-on voltage as large as 190mV was achieved in M-HBT device with $In_xGa_{1-x}As$ (x=0.15) base layer. This is due to the narrow band gap in base layer material in M-HBT structure. The band gap reduction caused by metamorphic InGaAs base in this study is much more effective than that by lattice-matched GaInNAs base layer reported in [1]. On the other hand, current gain in M-HBT was deteriorated and about the half of that in



conventional InGaP-HBT

Fig. 7. Base/collector breakdown voltage in M-HBT and conventional InGaP-HBT.

The subcollector and collector layer in M-HBT also can benefit from indium composition in its material. Figure 5 shows the relation between carrier concentration and carrier mobility in n-GaAs and n-$In_xGa_{1-x}As$ (x=0.05, 0.10, 0.15). The mobility in n-InGaAs is about 30% higher than that in n-GaAs at the same doping concentration. This is because of the small effective mass of electron in InAs component. High carrier mobility at high concentration in InGaAs lead to lower subcollector resistance in M-HBT. Contact resistance at metal/subcollector interface is also expected to be low because of the narrow band gap of InGaAs, which has smaller shottky barrier height against metal than GaAs. Both of low subcollector resistance and low contact resistance at metal/subcollector interface can contribute to reduce the series resistance in devices, leading to the smaller power dissipation in the HBT circuits. Owing to the high mobility in collector and low contact resistance, high frequency performance is also expected to improve in M-HBT.

Typical result of base/collector breakdown voltage testing for $In_xGa_{1-x}As$ (x=0.15) M-HBT is shown in figure 6. And the breakdown voltage as a function of indium composition in M-HBT is shown in figure 7. The breakdown voltage, which is defined as V_{BC} value to obtain 500 μA collector current in 150×150μm emitter device, is 27.2 (V) in x=0.15 device. It is almost the same, or slightly higher than InGaP-HBT at the same collector thickness. Figure 7 shows that breakdown voltage increases proportionally with indium composition. This is an unexpected result because hetero-junction device with low bandgap material, like InGaAs, usually breakdown at low electric field. Though we do not have an exact explanation for the high breakdown in InGaAs base/collector in M-HBT, this is an encouraging result when we think of M-HBT application in high power handling amplifiers.

CONCLUSIONS

We have demonstrated fabrication of low indium composition M-HBT with $In_xGa_{1-x}As$ (x=0.05, 0.10, 0.15) collector and base layer grown by MOVPE method. As high as 190 (mV) reduction of turn-on voltage is achieved in x=0.15 M-HBT device due to its narrow band gap in base layer. High electron mobility in InGaAs also decreases the resistivity of subcollector. On the other hand, breakdown voltage of M-HBT is maintained high, unexpectedly. Our results indicate that metamorphic technology can realize high efficiency HBT circuits while maintaining low production cost using GaAs substrate and matured GaAs manufacturing technology. Thus M-HBT is a promising solution for next generation HPA, as well as fiber-optic devices.

REFERENCES

[1] R. E. Welser, P. M. DeLuca, and N. Pan, IEEE Electron Device Lett. **21**, 554 (2000)

[2] T. Oka, T. Mishima, and M. Kudo, Appl. Phys. Lett. 78, 483 (2001)

[3] T. Tanaka, et al., 2000 GaAs MANTECH Technical Digest, pp. 89-92

[4] T. Tanaka, et al., 2001 GaAs MANTECH Technical Digest, pp. 61-63

[5] H. Yang, H. Wang, G. I. Ng, H. Zheng, and K. Radhakrishnan, 2001 IPRM Conference Proceedings, pp. 200-203