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MOCVD-GROWN InGaP/GaAs EMITTER DELTA DOPING HETEROJUNCTION BIPOLAR TRANSISTORS

K. F. YARN*

Far East College, Department of Electrical Engineering, Optoelectronic Semiconductor Center, Hsin-Shih, Tainan, Taiwan 744, Republic of China

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The influence of delta doping sheet at base-emitter (BE) junction for an InGaP/GaAs heterojunction bipolar transistor (HBT) with a 75 Å undoped spacer layer is investigated. A common emitter current gain of 235, an offset voltage as small as 50 mV and an Ic ideal factor of 1.01 are obtained, respectively. The use of delta doping sheet at BE junction results in a high gain and low offset voltage HBT. The improvement of current gain and offset voltage may be attributed to the reduction of BE potential spike by introducing a delta doping layer even without the BE junction passivation.

Keywords: Delta doping; Heterojunction bipolar transistor

1 INTRODUCTION

Heterojunction bipolar transistors (HBT) with AlGaAs/GaAs material have attracted considerable attention in microwave and digital application due to their high current handling capability and high speed [1]. The use of wide emitter bandgap introduces a band discontinuity ΔEv at the valence which suppresses the hole current injection from base to emitter. Thus, the current gain can be amplified about the order of $\exp(\Delta E_v/E_g)$ or a higher BE doping ratio is permitted due to the hole confinement. The increase of base doping level also reduces the base resistance that is very important in high frequency operation. However, there still exist some drawbacks and tradeoff associated with the potential spike resulting from the increase of conduction band discontinuity ΔE_c while the ΔE_v is increased.

Recently, many researchers have focused on the $In_{0.49}Ga_{0.51}P$/GaAs aluminum-free and lattice-match material system [2]. There are the following advantages in using InGaP/GaAs GaAs compared with AlGaAs/GaAs: (1) a higher $\Delta E_v/\Delta E_c$ ratio (2) a higher etching selectivity between InGaP and GaAs interface (3) a lower surface recombination velocity (4) a lower DX center density. The good performance of InGaP/GaAs related device implies the potential for future circuit applications [3]. Several methods have been considered to solve the problem of increased CE offset voltage ΔV_{CE}. Grinberg *et al.* [2] have proposed the concept of graded EB junction, which however, introduces the additional complexities

* Present Address: P. O. Box 345, Tainan, Taiwan 704, Republic of China

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and difficulties needed to the control of the graded layer during epitaxial growth. The main purpose of this study is to obtain a new method to effectively reduce the potential spike, while a high current gain at low collector region is simultaneously maintained. Two types of structures (sample A and B) with spacer layer are investigated, the difference between A and B is that sample A has a delta doping layer inserted at the EB junction. By using the delta-doped technique, the electron spike barrier is reduced while the effective hole barrier is still increased. Thus, the total ratio of spike barrier $\Delta E_v/\Delta E_c$ is enhanced. This implies an InGaP/GaAs HBT with a low CE offset voltage ΔV_{CE} and a high current gain can be achieved.

2 DEVICE STRUCTURE AND FABRICATION

The cross section of the fabricated device (sample A) grown by AIXTRON 2400 metal organic chemical vapor deposition (MOCVD) system is schematically shown in Figure 1. Epitaxial layers were subsequently grown on the (100)-oriented n^+-GaAs substrate. Si_2H_6, CBr_4 and DCpMg were used as *n*- and *p*-type dopants, respectively. The delta-doped n^+ layer with a high doping level of $1 \times 10^{12}\,cm^{-2}$ was inserted between the spacer (*i*-GaAs) and emitter. In order to compare the current–voltage (*I–V*) characteristics, InGaP/GaAs HBT without delta-doped layer (sample B) is also included.

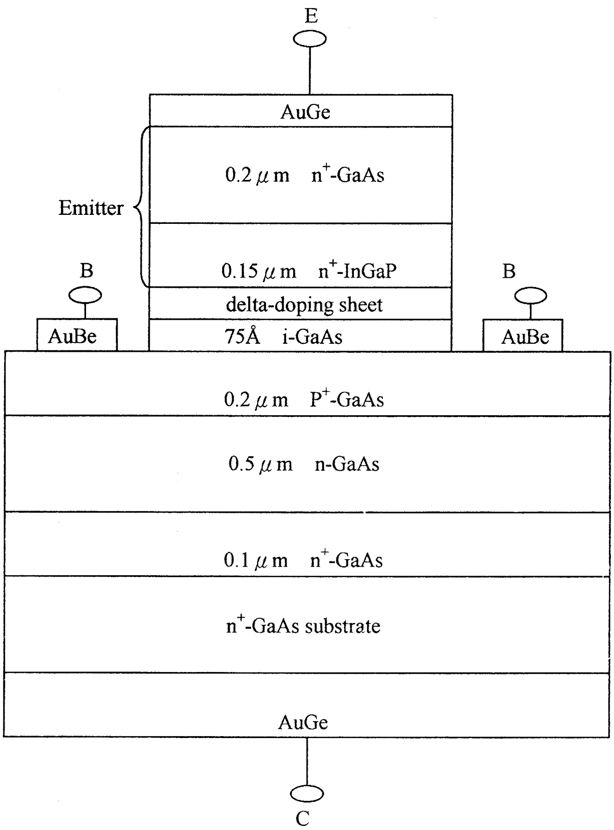

FIGURE 1 Schematic cross-section of delta-doped InGaP/GaAs HBT structure.

Deposited on the substrate is an n^+-GaAs buffer of 0.1 μm thickness with a doping level of $1 \times 10^{18}\,\mathrm{cm}^{-3}$. Then, about 0.5 μm of n-GaAs collector with a doping concentration of $5 \times 10^{16}\,\mathrm{cm}^{-3}$ was grown, followed by a 0.2 μm thick p^+-GaAs ($p = 1 \times 10^{19}\,\mathrm{cm}^{-3}$) base. The emitter layer consisted of a 75 Å undoped GaAs spacer, a delta-doped n^+ layer, a 0.15 μm-thick n^+-InGaP($n = 5 \times 10^{17}\,\mathrm{cm}^{-3}$) and finally a 0.2 μm-thick n^+-GaAs ($n = 1 \times 10^{18}\,\mathrm{cm}^{-3}$) cap layer was deposited. Mesa etching with a H_2SO_4:H_2O_2 60H_2O solution was used to define the device. A NH_4OH:H_2O_2:3H_2O solution was used to remove the GaAs top layer and then a HCl:H_2O solution with an etching rate of 25 Å/sec was used to etch the InGaP layer and exposed the base region. Au/Be was employed for the p^+-GaAs base contact. The emitter and the collector of the device, were both metallized with Au/Ge. The emitter area is 80 μm × 80 μm and the collector-to-emitter area ratio is 20. The DC *I–V* characteristics of the devices were measured at room temperature by HP 4145B.

3 RESULTS AND DISCUSSION

In order to enhance the performance of HBT, the EB potential spike plays an important factor to determine the CE offset voltage ΔV_{CE} [4]. Under the external bias, the potential spike of HBT with (sample A) and without (Sample B) a delta-doped sheet are investigated. The magnitudes of EB potential spikes are calculated by solving the Poissons' equation. The potential spike of sample B is about 195 mV at $V_{BE} = 1.0$ V, but that of sample A is negligible. The EB potential spike is nearly pulled down by the insertion of a delta-doped sheet.

The experimental Gummel plots of the studied device (sample A) with a delta-doped sheet are shown in Figure 2. The Ic ideal factor of 1.01 is near to unity, which is attributed to the elimination of the potential spike at the EB junction. On the other hand, the ideal factor of base current is 1.24 that is dominated by four components in base current: (1) injection current from base to emitter (2) recombination current in the neutral base (3) surface recombination current in the base (4) recombination current in the BE depletion region. It is obvious that the last three components are more important than the first component due to the large band discontinuity ΔE_v at EB junction. A previous report [5] shows that the space charge recombination current dominates the base current.

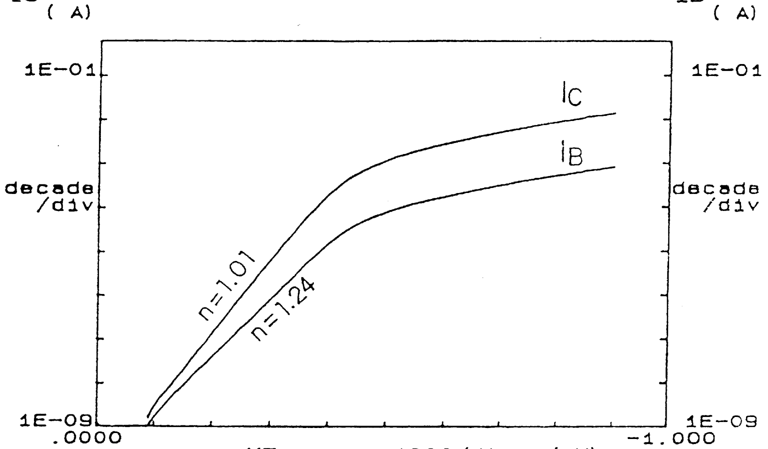

FIGURE 2 The ideal factor of collector and base current are 1.01 and 1.24, respectively.

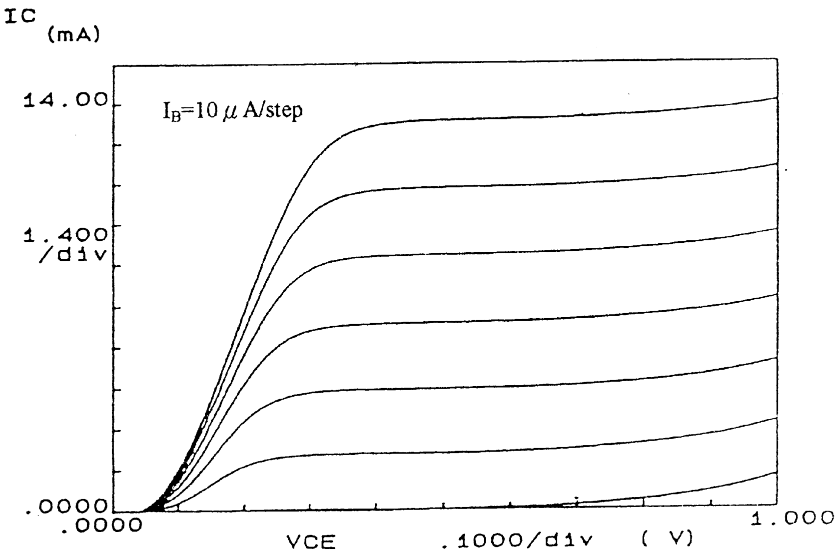

FIGURE 3 The typical common-emitter I–V characteristic of the delta-doped InGaP/GaAs HBT.

The electrical property of the common-emitter current–voltage (*I–V*) curve of sample A is shown in Figure 3. The maximum common-emitter current gain of 235 at $I_c = 14$ mA is better than that of studied conventional HBT ($\beta = 120$)(sample B) and double HBT($\beta = 150$) without the delta doping structure based on the InGaP/GaAs material system [6].

In addition, it is noteworthy that the offset voltage ΔV_{CE} is only 50 mV for sample A and this value is shown in Figure 4. This small offset voltage is obtained even without using grading or passivation structure and is due to the suppression of the EB potential spike by using the spacer and delta doping layers.

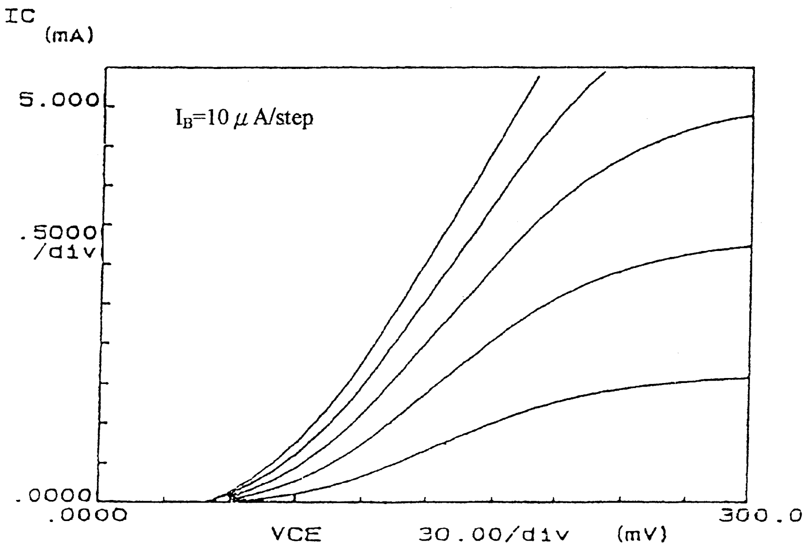

FIGURE 4 The offset voltage as low as 50 mV in common emitter configuration shown in low voltage range.

4 SUMMARY

An improved delta-doped InGaP/GaAs HBT with a 75 Å spacer layer is fabricated successfully. The use of delta doping sheet located at BE interface makes the potential spike negligible significantly. In this study, a common-emitter current gain of 235 with an offset voltage as low as 50 mV is achieved at the base thickness of 0.2 µm. The ideal factors of I_c and I_B are 1.01 and 1.24, respectively. Based on the idea of adding the delta doping sheet to suppress the BE potential spike, a high current gain and low offset voltage HBT will be developed by reducing the base thickness.

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