Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 467-469

Open-Base Multi-Emitter HBTs with Increased Logic Functions

K. Imamura, M. Takatsu, T. Mori, S. Muto, and N. Yokoyama
Fujitsu Laboratories Ltd.
10-1, Morinosato-Wakamiya, Atsugi, 243-01, Japan
Phone: +81-462-48-3111, Fax:+81-462-48-5193

This paper discribes the reduction of the operation voltage of ME-HBTs by increasing the emitter doping concentrations up to 3 x 10^{18} cm^{-3}. The effects of emitter doping on the I-V characteristics of the ME-HBTs were studied. We confirmed the room temperature operaton of the 3-input AND/NOR gates at the opertaion voltage of 2 V.

1. Introduction

Recently, we demonstrated a multi-emitter RHET that could reduce the number of elements used in logic circuits more drastically than conventional RHETs (1). But it's operation was limited to 77 K. Then, we proposed a multi-emitter HBT (ME-HBT), which is suitable for room-temperature operation (2). We found, however, that the supply voltage of the fabricated logic gates was too high at 7 V for practical circuits due to the large reverse breakdown voltage of the emitter-base junction. In this paper, we propose a method to overcome this problem.

2. Operation principle and structure of ME-HBT

The proposed device has more than two emitter electrodes, E1 and E2, and a collector electrode, but no base electrode, which simplifies the fabrication process. Figure 1 shows the operation energy band diagram of the ME-HBT. When E1 and E2 are the same potential, both high or both low [A, C], the emitter-base junction is in thermal equilibrium, so electrons are not injected into the base. When we increase the potential differnce between E1 and E2 by applying a positive bias to E2, the base potential decreases with respect to E1. Fianlly, electrons are injected from E1 into the base and a collector current flows [B]. The transistor is switched by the potential difference between the two emitters. In B), the

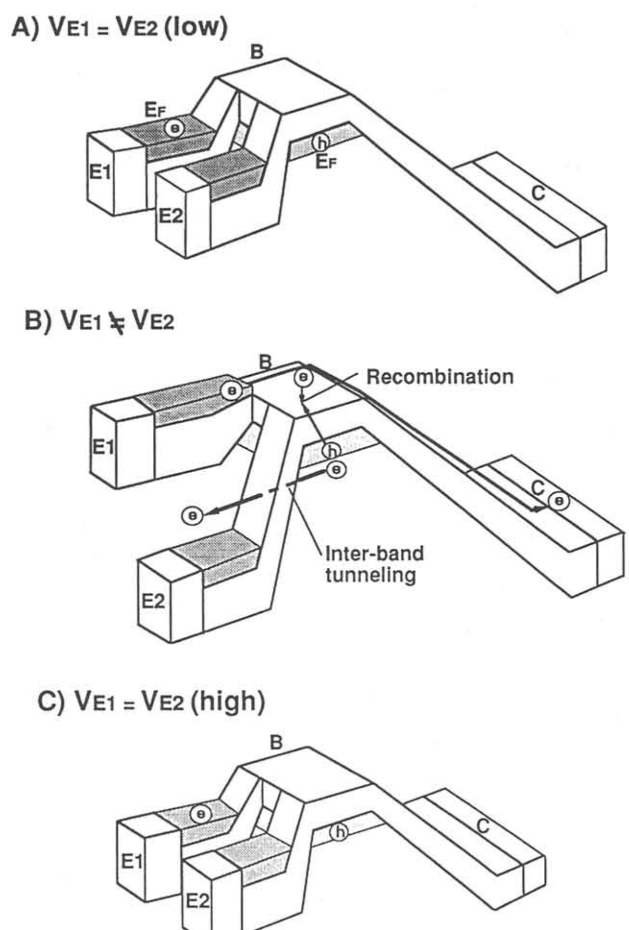

Figure 1 The operation band diagram of the ME-HBT.

negative charge produced by the recombination of electrons in the base layer must flow to E2. We suggest that the use of high emitter doping increases the interband tunneling because it increases the maximum electric field between the emitter-base p-n junction. We studied the dependence of the electrical charcteristics of InGaAs/InP ME-HBTs on the doping concentration, N_D, in the emitter layer. Figure 2 shows the structure of the InGaAs/InP ME-HBT. InGaAs and InP layers were grown on InP substrate by MOCVD. The thickness of the base layer was 80 nm and the doping concentration was 3 x 10^{19} cm^{-3}. The doping concentraion of the InP emitter layer was 0.5, 1, 2, and 3 x 10^{18} cm^{-3}, respectively. Emitter and collector electrodes were Cr/Au non-alloyed ohmic contacts.

We also fabricated a conventional HBTs with a base electrode (SE-HBTs) on the same wafers.

3. Experimental results

To evaluate the p-n junctions, we plotted the emitter-base I-V characteristics of a conventional SE-HBT. Figure 3 shows the emitter-base I-V characteristics of the SE-HBT. The reverse breakdown voltage decreases with increasing N_D. The forward I-V characteristics do not depend significantly on the emitter doping concentration. The reverse breakdown voltage when N_D is 3 x 10^{18} cm^{-3} is about 1/6 of that of the conventional one (N_D is 5 x 10^{17} cm^{-3}).

Figure 4 shows the common-emitter current gain as a function of the emitter doping concentration, N_D. The current gain decrease with increasing N_D, and then inclined to saturate to about 20 at N_D of over 1 x 10^{18} cm^{-3}.

Figure 5 shows a common-emitter collector I-V characteristics of the ME-HBT with N_D = 3 x 10^{18} cm^{-3}. We can control the collector current of a ME-HBT by varying the base current in the same way as for SE-HBTs, and we obtained a current gain of over 20. In contrast, increasing the voltage difference between the emitter electrodes to about 1.2 V, turns the collector current on. The collector current turn-on voltage (1.2 V) corresponds to the sum of the emitter-base forward turn-on vpltage (0.6 V) and the reverse breakdown voltage (0.6 V) shown in Figure 3. We can extend these characteristics to ME-HBTs with more than 3 emitters for various logic applications.

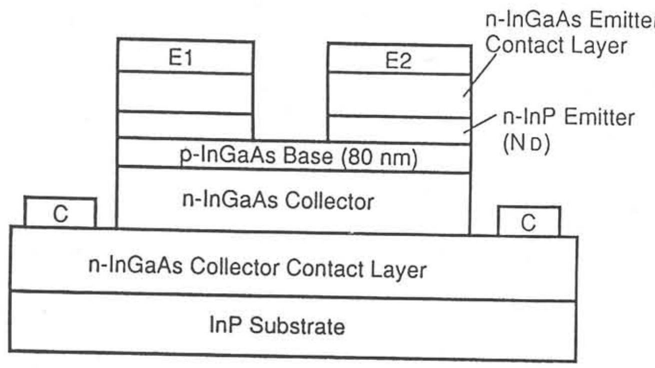

Figure 2 Structure of the InGaAs/InP ME-HBT.

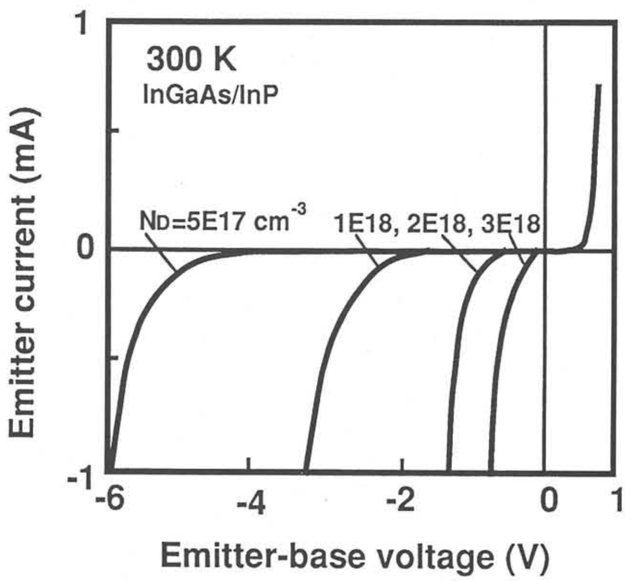

Figure 3 Emitter-base I-V characteristics of the SE-HBT at 300 K.

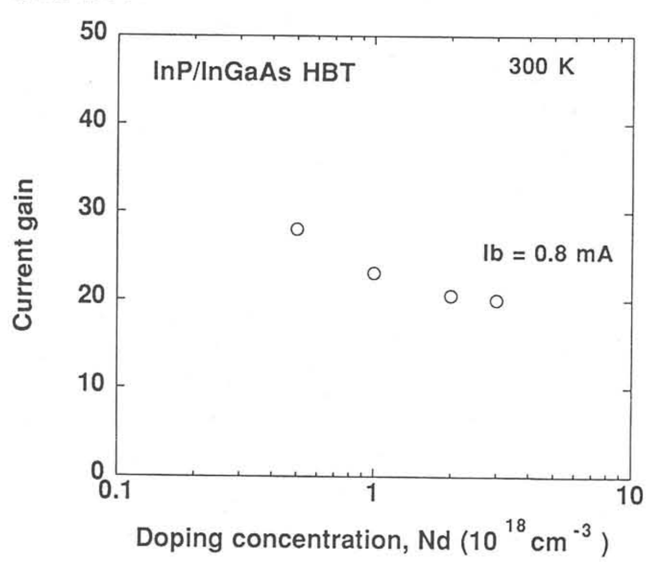

Figure 4 Common-emitter current gain of the SE-HBTs as a function of emitter doping concentration, N_D.

Using a 3-emitter ME-HBT, we constructed a basic logic gate, a 3-input AND/NOR. Figure 6 shows the 3-input AND/NOR gate formed using a ME-HBT and its operation at 300 K (ND = 3 x 10^{18} cm^{-3}).The load resistance is 1 kΩ. The output of this gate is high when the ME-HBT is off, this condition is satisfied only when all inputs are at the same logic level. note that the supply voltage is 2 V, which is 2/7 of the previously reported results (2). Number of elements needed for a 3-input AND/NOR gate formed using a ME-HBT is about one tenth that of the conventional bipolar ECL and/or C-MOS logic gates.

4.Summary

We have proposed and demonstrated a new ME-HBT structure with highly doped emitter layer. We demonstarted room-temperature opertaion of AND/NOR gates using only one ME-HBT. The opertaion voltage was reduced to 2 V by using a 3 x 10^{18} cm^{-3} emitter doping. Our results indicate that the ME-HBTs are candidates for future electron devices.

Acknowledgements: We thank H. Tamura, T. Fujii, T. Nakamura and H. Ishikawa for their encouragement. We also thank T. Adachihara, M. Yamaguchi, T. Iwai, and Y. Shigematsu for their suppot and advice.

References

(1) M. Takatsu, K. Imamura, T. Mori, T. Adachihara, S. Muto, N. Yokoyama,.Technical digest of ISSCC (1994).

(2) K. Imamura, M. Takatsu, T. Mori, Y. Bamba, S. Muto, and N. Yokoyama., Electronics Letts. Vol.30, No.5 pp.459-450 (1994).

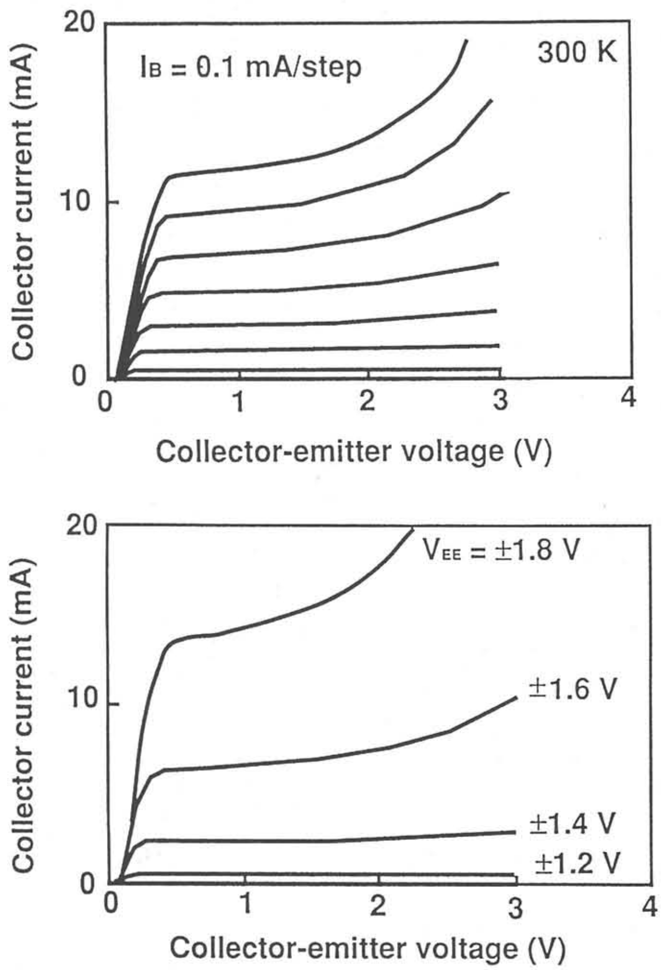

Figure 5 Common-emitter collector I-V characteristics of the ME-HBT (N_D = 3 x 10^{18} cm^{-3}).

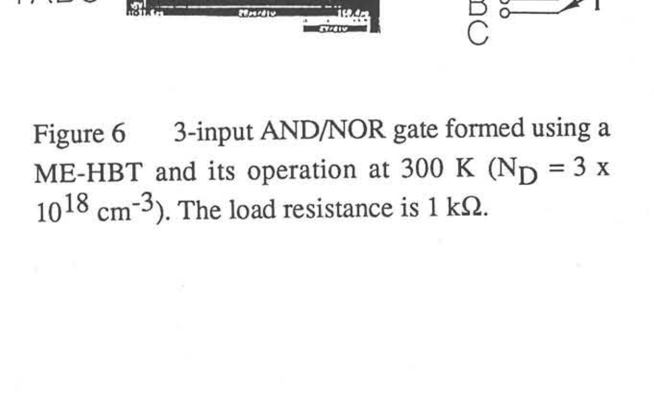

Figure 6 3-input AND/NOR gate formed using a ME-HBT and its operation at 300 K (N_D = 3 x 10^{18} cm^{-3}). The load resistance is 1 kΩ.