InGaN/GaN Double Heterojunction Bipolar Transistor Grown by Metalorganic Vapor Phase Epitaxy

Toshiki Makimoto, Kazuhide Kumakura and Naoki Kobayashi

NTT Basic Research Laboratories,
3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0198, Japan
Tel.: +81–46–240–3421, Fax: +81–46–240–4729, e-mail: makimoto@will.brl.ntt.co.jp

Group-III nitrides are promising materials for electronic devices that operate under high temperatures and/or require high power, so there have been several reports of AlGaN/GaN heterojunction bipolar transistors (HBTs) [1-3] along with AlGaN/GaN field effect transistors. In these HBTs, room-temperature hole concentrations of the base layers are lower than $1x10^{18}$ cm^{-3} due to a large acceptor activation energy (170 meV) of Mg atoms in Mg-doped GaN, which will result in higher contact resistance and limit high frequency operation. For the device application, room-temperature hole concentrations higher than $1x10^{18}$ cm^{-3} are desirable. In the HBT fabrication process, the dry etching processes are commonly used, because GaN is chemically inert against wet etchants at room temperature. However, these dry etching processes tend to damage the surfaces that become strongly n-type due to the N-deficiency. [4] This is a great problem for the etching of p-GaN base surfaces, because it is difficult to form p-type Ohmic contacts on the etched surfaces. Recently, we have reported that Mg-doped InGaN layers show high hole concentrations above $1x10^{18}$ cm^{-3} at room temperature, i.e., maximum hole concentration of $7x10^{18}$ cm^{-3} was observed for Mg-doped $In_{0.14}Ga_{0.86}N$. [5] These high hole concentrations are ascribed to lower acceptor activation energies and higher electrical activity of Mg atoms in InGaN. We have also reported that In atoms doped in Mg-doped GaN reduce the etching damage to form better p-type Ohmic contacts on the etched surface. [6] Considering lower bandgap of InGaN, Mg-doped InGaN is, therefore, a suitable material for a base layer of group-III nitrides based HBTs. Here, we propose and report an InGaN/GaN double heterojunction bipolar transistor (DHBT) for the first time.

Figure 1 shows the layer structure of an InGaN/GaN DHBT grown by metalorganic vapor phase epitaxy (MOVPE). In this work, the double heterojunction structure was used for the following two reasons. One is that wider bandgap of the GaN collector has an advantage over high power operation compared with the InGaN collector. The other is that HBTs with InGaN collectors show degraded I-V characteristics in the base-collector diodes due to their large leak current. On the other hand, for the DHBT structures, the spike at the conduction-band edge due to the conduction band offset prevents electrons from passing through the base to the collector, resulting in lowering current gain and degraded HBT characteristics. To eliminate this electron blocking effect at the base and collector interface, a graded InGaN layers and a 30-nm n-GaN (Si : $1x10^{18}$ cm^{-3}) , which lowers the energy potential for electrons, were inserted between the base and collector as shown in Fig. 1. Using low-pressure MOVPE, a GaN buffer layer was deposited at 500°C on the c-face sapphire substrate. Next, a 2-µm-thick undoped GaN buffer and Si-doped GaN layers were grown at 1000 ^{o}C. Then, an undoped InGaN spacer, a Mg-doped InGaN base, an undoped InGaN spacer and Si-doped GaN emitter layers were grown at 780 ^{o}C. The source materials were triethylgallium, trimethylindium and ammonia. The p-type dopant source was bis-cyclopentadienyl-magnesium (Cp_2Mg). The In mole fraction (x) in the base layer was 0.25. Separate room-temperature Hall measurements revealed a hole concentration.of $4x10^{18}$ cm^{-3} in the base layer. The base mesa was defined by electron cyclotron resonance etching using Cl_2. Pd/Au and Al/Au metals were used for p- and n-type Ohmic contacts, respectively.

Figure 2 shows the common emitter I-V characteristics with a base current of 2 µA/step. The emitter size was relatively large as 30µm x 30µm. The maximum current gain of 1.1 was observed at room temperature. This relatively low current gain and unsaturated I-V characteristics might be ascribed to the electron blocking effect. Furthermore, large and scattered V_{CE} offsets are ascribed to high lateral resistance of the base, as pointed out in Ref. [3]. Therefore, optimal layer structures (base layer thickness, base doping concentration, and a layer structure between the base and collector) and device design (the device sizes and the distance between base and collector contacts) are expected to improve their InGaN/GaN DHBT characteristics further.

References

[1] L. S. McCarthy, P. Kozodoy, S. P. Denbaars, M. Rodwell, and U. K. Mishra, 25th International Symposium on Compound Semiconductors, Nara, Japan, Oct. 1998.

[2] F. Ren, C. R. Abernathy, J. M. Van Hove, P. P. Chow, R. Hickman, J. J. Klaasen, R. F. Kopf, H. Cho, K. B. Jung, J. R. La Roche, R. G. Wilson, J. Han, R. J. Shul, A. G. Baca, and S. J. Pearton, MRS Internet J. Nitride Semicond. Res. **3**, 41 (1998).

[3] J. B. Limb, L. McCarthy, P. Kozodoy, H. Xing, J. Ibbetson, Y. Smorchkova, S. P. DenBaars, and U. K. Mishra, Electron. Lett. **35**, 19 (1999).

[4] S. J. Pearton and R. J. Shul : *Wet and Dry Etching of GaN*, ed. J. I. Penkove and T. D. Moustakas (Academic Press, NY 1998), in GaN I.

[5] K. Kumakura, T. Makimoto, and N. Kobayashi, Jpn. J. Appl. Phys. **39**, L337 (2000).

[6] T. Makimoto, K. Kumakura, and N. Kobayashi, ICMOVPE-X, Tu-P43, (2000) Sapporo.

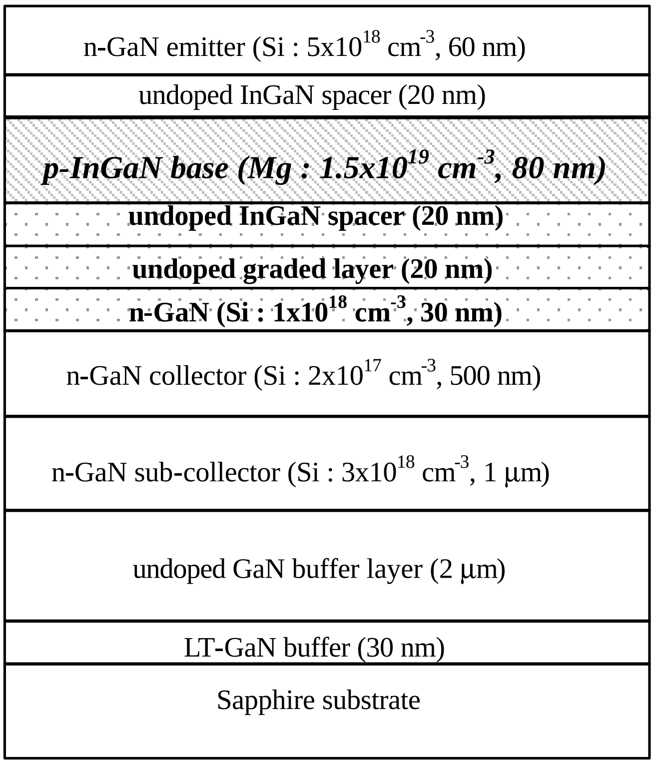

Fig. 1 : Layer structure of an InGaN/GaN DHBT grown by low-pressure MOVPE.

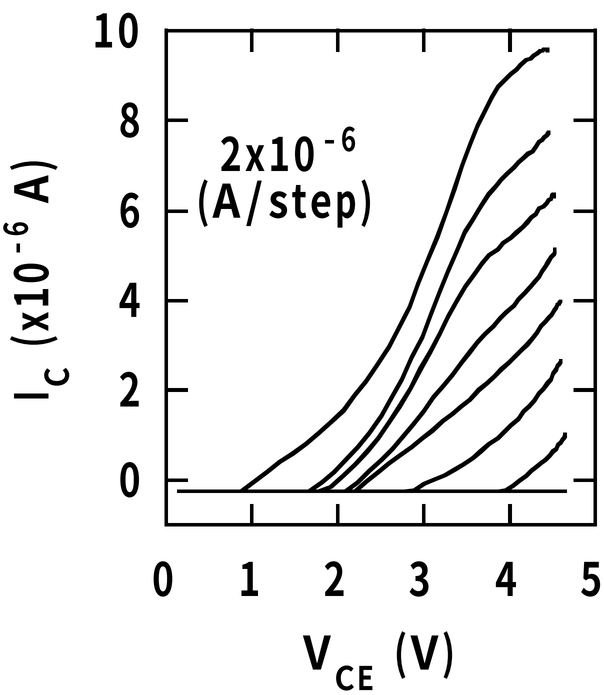

Fig. 2 : Common emitter I-V characteristics of an InGaN/GaN DHBT at room temperature.