# A Composite-Collector InGaP/ GaAs HBT with High Ruggedness for GSM Power Amplifiers

Takaki Niwa, Takashi Ishigaki, Hidenori Shimawaki and Yasunobu Nashimoto

Compound Semiconductor Department, NEC Compound Semiconductor Devices, Ltd.
Seiran 2-9-1, Otsu, Shiga, 520-0833, Japan

*Abstract* — **This paper reports on the InGaP/ GaAs HBT with the GaAs/ InGaP composite collector for a GSM power amplifier. The GaAs/ InGaP composite collector enables to pass the ruggedness test with SWR=10:1 at $V_{CE}$ >5V, keeping the total collector thickness of around 900nm and the high power added efficiency (PAE). The load-pull measurement result for multi-cell HBTs with total emitter size of 7200μm$^2$ reveals the PAE of 74% at Pout=35dBm and $V_{CE}$=3.5V for the composite collector.**

## I. Introduction

An InGaP/GaAs heterojunction bipolar transistor (HBT) has been widely used for wireless handsets, because an HBT has excellent features of single-voltage operation and high power density with high efficiency. For using an HBT as a GSM power amplifier, it is required that a power amplifier does not fail at high load voltage-standing-wave-ratio (SWR) conditions that an antenna fault causes. In the condition of this ruggedness test, very high voltage swing to more than 15V and high current swing are created on the power amplifier, because a GSM handset has features of high output power handling of 3W and no isolator between the power amplifier and the antenna. This requirement for the ruggedness is so hard that several SWR protection circuits were proposed [1,2].

To satisfy this requirement, high collector-emitter breakdown voltage during operation is needed. The increase in a collector thickness more than 2μm could improve the breakdown voltage [3]. However, thicker collector degrades the PA performance, which is caused by the increase in the on-resistance and the degradation of cut-off frequency. These are caused by the decrease in the electric field in the collector and the increase in the collector transit time, respectively. Thicker collector also leads to the process problem due to the high topology.

In this paper, we present the InGaP/GaAs HBT for a GSM power amplifier with high ruggedness performance. This HBT has a novel GaAs/InGaP composite collector structure that enables to pass the ruggedness test of SWR = 10:1 at $V_{CE}$ > 5V without much degradation of the RF performance and large collector thickness.

## II. Device Design for High Breakdown Voltage

The collector-emitter breakdown voltage during operation was simulated for designing the collector layer structure. The simulated breakdown voltage is shown in Fig. 1. The layer structure using this simulation consists of a 500nm GaAs subcollector layer ($5x10^{18}cm^{-3}$ doped), an 80nm GaAs base layer ($4x10^{19}cm^{-3}$ doped), a 30nm $In_{0.48}Ga_{0.52}P$ emitter layer ($3x10^{17}cm^{-3}$ doped), GaAs and InGaAs emitter contact layers. The collector layer is a widely used GaAs layer, which consists of an only GaAs layer.

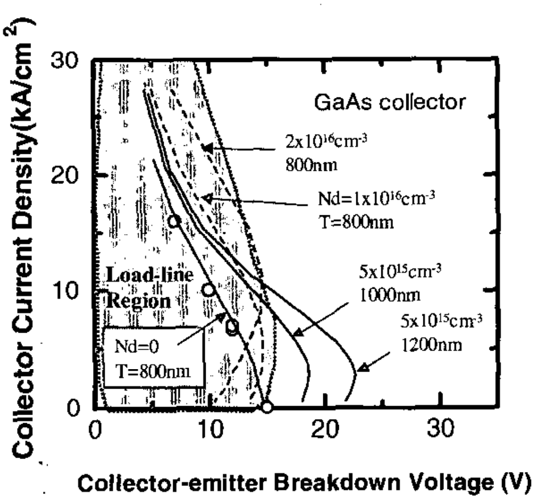


Fig. 1. Simulated collector-emitter breakdown voltages for GaAs collector structure. The circle reveals the measured pulse-mode breakdown voltage.

In this simulation, a junction temperature is constant at any bias points. In the RF operation, a junction temperature is almost constant and determined by the DC power although voltage and current swings are created. The circle marker in Fig.1 reveals the measured pulse-mode breakdown voltage for 800nm I-GaAs collector



0-7803-7695-1/03/$17.00  

(doping density Nd=0). In this measurement, the pulsed base-current is used for preventing the increase in the junction temperature. The pulse width is 100μsec. This breakdown voltage is 2-3V lower than DC-sweep breakdown voltage since an avalanche breakdown voltage increases as a junction temperature increases. The simulated breakdown voltage is in good agreement with the pulse-mode breakdown voltage.

The simulated dynamic loadline is also shown in Fig. 1. The loadline exists in the patterned area of Fig.1 under the ruggedness test of SWR =10:1(all phase) at $V_{CE}$=5V. The input power was set to the output power of 35dBm at $V_{CE}$=3.5V. To pass the ruggedness test with SWR of 10:1 at $V_{CE}$=5V, the breakdown voltage line needs to exceed this dynamic loadline.

### A. GaAs Collector

In Fig.1, the increase in the collector thickness enables to improve the collector-emitter breakdown voltage at low collector current density (Jc), while the breakdown voltage at high Jc is not sensitive to the increase in collector thickness. The increase in a collector doping density improves the breakdown voltage at high Jc. However it degrades the breakdown voltage at low Jc. The higher doping density also causes the degradation of RF gain due to the increase in the base-collector capacitance. Therefore, the HBT with the GaAs collector is difficult to pass the ruggedness test of SWR=10:1 at $V_{CE}$=5V when the collector thickness is around 1000 nm. To pass the ruggedness test, the improvement of the breakdown voltage at high Jc is important.

### B. Composite Collector

We propose the novel GaAs/InGaP composite collector structure for improving the breakdown voltage at high $J_c$. The composite collector layer structure consists of two layers, a GaAs layer and an InGaP layer. The InGaP layer is inserted between the GaAs and the subcollector layer. This InGaP layer improves the breakdown voltage at high Jc. This is because the high electric field is formed near the collector-subcollector interface at high Jc and, the electron and hole impact ionization coefficients in InGaP are 1/100 smaller than those in GaAs [4]. The ordered InGaP is used in the composite collector for minimizing the conduction band discontinuity.

The composite collector structure is also used to suppress the degradation of PAE due to the increase in the collector resistance. The InGaP collector, which consists of an only InGaP layer without a GaAs layer, causes the much degradation of PAE than the composite collector. The simulation result for the collector resistivity is shown in Fig. 2. The base-emitter voltage is 1.35V and the collector-emitter voltage is 0.01V. The conduction band discontinuity between GaAs and InGaP is 0eV. The corrector resistivity r' was calculated from (1) [5]

$$r' = \frac{d}{dx_0}\left(\frac{dE_F'}{dI_C}\right)\Big|_{x_0=x} \quad (1)$$

where $E_F'$ is the quasi-Fermi level. The collector resistance can be obtained by integrating the profile of the collector resistivity.

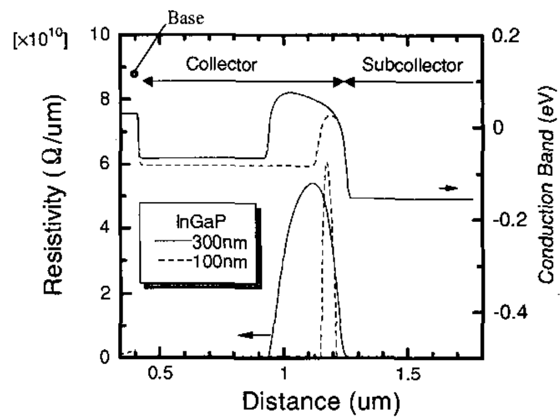


Fig. 2. Simulated resistivity in the collector region for the composite collector.

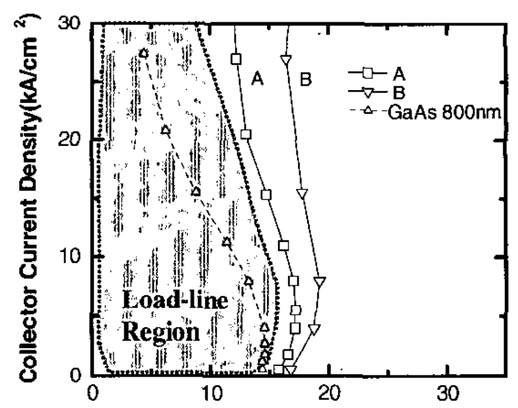


Fig. 3. Simulated breakdown voltage for the composite collector structure A and B.

The high resistivity region is formed in the InGaP layer as shown in Fig.2. The thicker InGaP layer in the composite collector causes the increase in the collector resistance.

TABLE II

SUMMARY OF RUGGEDNESS TEST RESULTS

| | $V_{CE}$=4.25V | 5.00V | 5.50V | 5.75V |
|---|---|---|---|---|
| I-GaAs collector (800nm) | 5:1 | | | |
| Structure A | 10:1 | 10:1 | 6:1 | |
| Structure B | 10:1 | 10:1 | 10:1 | 10:1 |

Figure 3 shows the simulated breakdown voltage for the composite collector structure. The collector structures are a 700 nm GaAs/ a 200 nm InGaP for the Structure A, and a 700 nm GaAs/ a 300nm InGaP for the Structure B. The composite collector structures A and B are expected to pass the ruggedness test with SWR = 10:1 at $V_{CE}$= 5V.

## III. DC BREAKDOWN MEASUREMENT

The measured breakdown voltage is shown in Fig. 4. The pulsed base current was used. The pulse width and periodicity were set to 100 μs and 1ms, respectively. The unit cell HBTs with an emitter size of 3um x20um x2 were used.

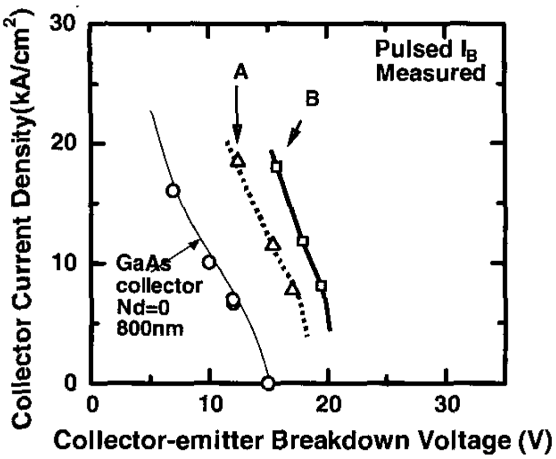


Fig. 4. Measured breakdown voltage for the i-GaAs collector and the composite collectors.

The measurement results reveal that the composite collector structure A and B enable to improve the breakdown voltages at all Jc. The breakdown voltage for the structure B is higher than that for the structure A since the InGaP layer in the composite collector for the structure B is thicker than that for the structure A.

The base-open breakdown voltage ($BV_{CEO}$) and the emitter-open breakdown voltage ($BV_{CBO}$) are listed in Table I. These breakdown voltage is measured with the conventionally used DC sweep.

**TABLE I**

DC-SWEEP BREAKDOWN VOLTAGE

| | GaAs collector | Composite collector | |
|---|---|---|---|
| | Non-dope, 800nm | Structure A | Structure B |
| $BV_{CEO}$ | 15.0V | 16.9V | 18.5V |
| $BV_{CBO}$ | 21.0V | 26.5V | 29.1V |

## IV. RUGGEDNESS TEST AND PA CHARACTERISTICS

Ruggedness test was performed for the multi-cell HBT. The total emitter size is 7200μm². The input power was set to the output power of 35dBm at $V_{CE}$ of 3.5V. This input power was used during the ruggedness test at $V_{CE}$=4.25V to 6V, which causes higher output power as the increase in $V_{CE}$. The experimental results are summarized in Table II. The composite collectors A and B can pass the ruggedness test with SWR= 10:1 at $V_{CE}$= 5V, while the conventional GaAs collector (non-doped, 800nm) fails at this condition. Furthermore, Structure B can pass the ruggedness test at $V_{CE}$=5.75V. Therefore, our composite collector HBT cannot be easily failed.

TABLE III

SUMMARY OF LOAD-PULL MEASUREMENTS

| $V_{CE}$=3.5V, Pout=35dBm | Gain (dB) | Ic (mA) | PAE (%) |
|---|---|---|---|
| I-GaAs collector | 10.8 | 1104 | 76 |
| Structure A | 10.8 | 1154 | 74 |
| Structure B | 10.0 | 1147 | 73 |

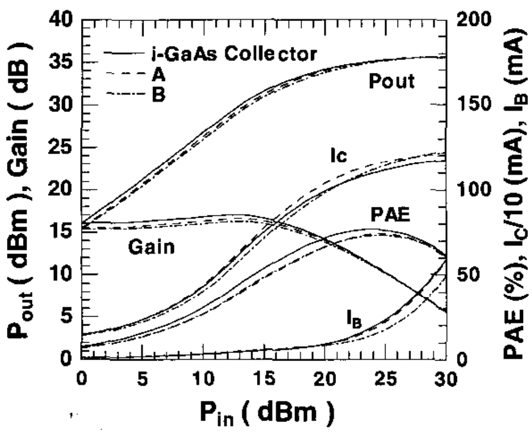


Fig. 5. Load-pull measurement results for GSM spec.

The load-pull measurement results are summarized in Table III and Fig.5. The operating frequency is 900MHz and $V_{CE}$ is 3.5V. The power added efficiencies (PAE) for structure A and B are only 2-3 % smaller than that for the conventional GaAs collector (non-doped, 800nm) at an output power of 35dBm. This degradation is mainly caused by the increase in the collector resistance.

## V. CONCLUSION

The InGaP/GaAs HBT with a novel GaAs/InGaP composite collector for a GSM power amplifier was presented. The GaAs/ InGaP composite collector enables to pass the ruggedness test of SWR=10:1 at $V_{CE}$=5V, keeping the total collector thickness of around 900nm. This is because the avalanche breakdown near the collector-subcollector interface is effectively suppressed by using the InGaP layer. The total collector thickness is not much larger than 1μm, which little leads to the process problem due to the high topology. The composite collector also enables to suppress the degradation of PAE due to the increase in the collector resistance. The result of the collector-resistivity simulation reveals that the InGaP layer in the composite collector causes the increase in the collector resistance. This reveals that the InGaP collector, which consists of an only InGaP layer, causes much more degradation of PAE compared with the composite collector. As a result of the load-pull measurement, the high PAE of 74% is obtained for the composite collector, which is only 2% smaller than that for the conventional GaAs collector at an output power of 35dBm, 900MHz and $V_{CE}$ of 3.5V. These results reveal that the HBT with the GaAs/InGaP composite collector is suitable for a GSM power amplifier.


## ACKNOWLEDGEMENT

The authors would like to thank Dr. K. Wasa for his encouragement throughout this work, and K. Azuma and N. Kurosawa for the technical discussion and the large support in fabricating, and R. Yamamoto, F. Ono, F. Harima, and K. Imagawa for the technical discussion. The authors also wish to acknowledge H. Ishiuchi for his support in fabricating, and K. Ueda for his encouragement throughout this work.


## REFERENCES


[1] K. Yamamoto, S. Suzuki, K. Mori, T. Asada, T. Okuda, A. Inoue, T. Miura, K. Chomei, R. Hattori, M. Yamanouchi, and T. Shimura, "A 3.2-V Operation Single-Chip Dual-Band AlGaAs/GaAs HBT MMIC Power Amplifier with Active Feedback Circuit Technique," *IEEE J. Solid-State Circuits*, vol 35, no.8, pp.1109-1120, August 2000.

[2] J. Pusl, S. Sridharan, P. Antognetti, D. Helms, A. Nigam, J. Griffiths, K. Louie and M. Doherty, "SiGe Power Amplifier ICs with SWR Protection for Handset Applications," *Microwave Journal*, pp.100-113, June 2001.

[3] D. Hill and T.S. Kim, "28V thermal-impedance HBT with 20W cw output power," *IEEE Trans. Microwave Theory and Tech.*, vol. 45, pp.2224, 1997

[4] S.-L. Fu, T.P.Chin, M.C. Ho, C. W. Tu, and P. M. Asbeck, "Impact ionization coefficients in (100) GaInP," *Appl. Phys. Lett.*, vol. 66, No.25, pp3507-3509, June 1995.

[5] T. Niwa, Y. Amamiya, M. Mamada, and H. Shimawaki, "High-ft AlGaAs/ InGaAs HBTs with reduced emitter resistance for low-power-consumption, high-speed ICs," *Inst. Phys. Conf.*, No.162, pp.309-312, October 1998.