# A Super Ruggedness InGaP/GaAs HBT for GSM Power Amplifiers

Yuefei Yang, Byounguk In, Yaochung Chen, Chanh Nguyen, Daniel Hou, Joe Zhou, Kevin Feng, Wing Yau and Dave Wang
Global Communication Semiconductors, Inc., 23155 Kashiwa Court, Torrance, CA 90505

Phone: (310) 530-7274, Fax: (310) 530-7279, Email: yyang@gcsincorp.com

**Keywords: InGaP/GaAs HBT, power amplifiers, GSM, VSWR.**

**Abstract**

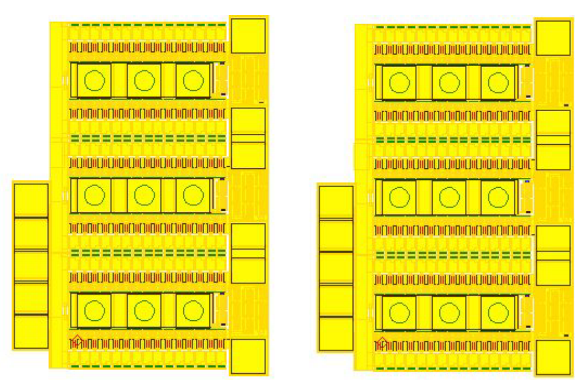
**A 4W super ruggedness InGaP/GaAs HBT for GSM power amplifier applications is presented. With improved epi-structure, layout and process, the device can be survived at 25:1 VSWR. To our knowledge, this is the highest ruggedness achieved for a 4W InGaP/GaAs HBT. In addition, the device shows good power performance with typical 36 dBm output power, 18 dB linear gain and 64% PAE at 900 MHz and 35 dBm output power, 15 dB linear gain and 60% PAE at 1800 MHz, respectively. This device is excellent candidate for not only GSM but also DCS/PCS PA applications.**

## INTRODUCTION

InGaP/GaAs Heterojunction Bipolar Transistors (HBTs) are widely used for power amplifiers in wireless communication systems, due to their high power handling capability, high efficiency, good linearity, excellent reliability and single-voltage supply [1]. As is well known that the GSM technology uses signal waveforms that have constant envelope amplitude. The transmitter power amplifier can be driven into 4 to 6 dB compression to maximize the power-added-efficiency (PAE). However, facing the unpredictable antenna load while operating in such deep compression, the power amplifier is at risk of being damaged due to high voltage standing wave ratio (VSWR) mismatch at which very high current swing ($I_C$ ~ 3 A) and very high voltage swing ($V_{CE}$ ~ 12 V) can be created. Therefore, power amplifiers for GSM applications require not only high output power (~36dBm) and high PAE (> 60%), but high ruggedness as well. However, InGaP/GaAs HBTs sometimes shows ruggedness problem if collector structure, device layout and process are not properly designed. In order to improve device ruggedness, varieties of collector design have been studied [2], [3]. However, the reported ruggedness improvement was only from VSWR of 5:1 to 10:1. In this paper, we will present an improved 4W InGaP/GaAs HBT with load VSWR greater than 25:1 at 5V while devices keep small size and high output power and efficiency.

## DEVICE FABRICATION

4W InGaP/GaAs HBTs were fabricated with GCS optimized epi-structure, layout and process. The HBT material structure includes InGaAs/GaAs emitter cap layer, InGaP emitter layer, C-doped GaAs base layer, $n^-$ GaAs collector layer and $n^+$ GaAs subcollector layer. The collector was designed to have not only high breakdown voltage but also wide safe operation area. The devices were fabricated using a two-mesa structure and two-level metal (M1 and M2) interconnections with 5.5 µm plated Au as low-loss second level metal. Ion implantation was used for subcollector isolation. MIM capacitors with unit capacitance of 360 pF/mm$^2$, stacked MIM capacitors with unit capacitance of 720 pF/mm$^2$, and thin film resistors with sheet resistance of 50 Ohm/sq were used for MMIC designs. Polyimide was used as low loss dielectric layer between M1 and M2. Through-wafer vias were used for emitter ground. A set of process control monitor (PCM) patterns was also designed and processed to monitor device DC performance and process parameters. Backside process includes wafer bonding and thinning to 4 mil; backside through-via etching and backside metal plating. Two 4W HBT power cells with different layouts for chip size and ruggedness trade off were fabricated. Fig. 1 shows layout of the two devices. The both devices have the same total emitter size of 7200 µm$^2$. The numbers of fingers, finger sizes and chip sizes are listed in Table 1.



Device A Device B

Fig. 1. Layout of 4W Device A and B.

Table 1. 4W device size information and power performance

| Device | Unit finger size [$\mu m^2$] | Total # of fingers | Device size including output pads [$\mu m^2$] | $G_{max}$ [dB] | Max PAE [%] | Pout @ Max PAE [dBm] | Freq [MHz] |
|---|---|---|---|---|---|---|---|
| Device A | 2x20x2 | 90 | 550x910 | 18.1 | 63.5 | 36.3 | 900 |
| Device B | 2x30x2 | 60 | 450x930 | 18.2 | 65.2 | 35.8 | 900 |
| Device A | 2x20x2 | 90 | 550x910 | 15.0 | 60.0 | 35.0 | 1800 |

## Device DC and RF Performance

The key device parameters are shown in Table 2. I-V curves with safe operation area for a device with emitter size of 2x20x15 $\mu m^2$ is shown in Fig. 2. The wide safe operation area is obtained due to proper collector design, layout and process, which is the key to improve ruggedness. Fig. 3 shows the I-V curves of a 4W device at CW mode. The peak collector current reaches up to 4A that is equivalent to current density of 58 KA/cm$^2$ without device damage. The current gain suppression at high voltage region is typically due to the self-heating effect at CW mode.

Table 2. Key device parameters of high ruggedness InGaP/GaAs HBT process.

| Parameters | Unit | Typical Values |
|---|---|---|
| Current Gain @ 1KA/cm$^2$ | | 70 |
| BVceo @ 2KA/cm$^2$ | V | 18.5 |
| BVcbo @ 2KA/cm$^2$ | V | 35 |
| BVebo @ 2KA/cm$^2$ | V | 6.5 |
| Ft @ 25KA/cm$^2$ | GHz | 30 |
| Fmax @ 25KA/cm$^2$ | GHz | 60 |

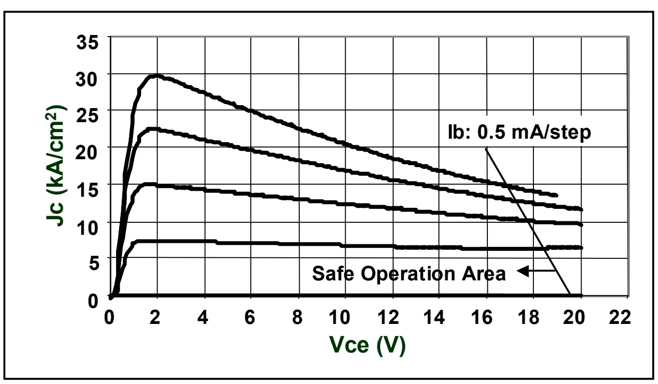



Fig. 2. I-V curve for a 2x20x15 $\mu m^2$ HBT.

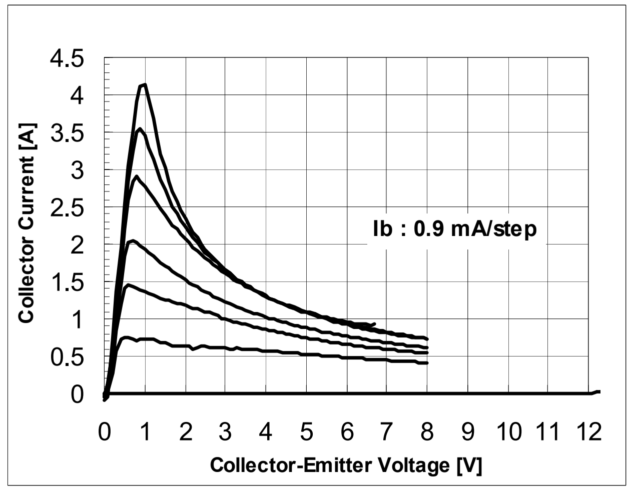



Fig. 3. I-V curves of a 4W device A at CW mode.

Fig.4 shows the Ft and Fmax versus collector current density for a single finger device with 2x20 $\mu m^2$ emitter size. Ft and Fmax are 30GHz and 60GHz at Vc of 3V and Jc of 25KA/cm$^2$, respectively. Peak Fmax >60GHz is good enough for GSM and PCS/DCS power amplifiers.

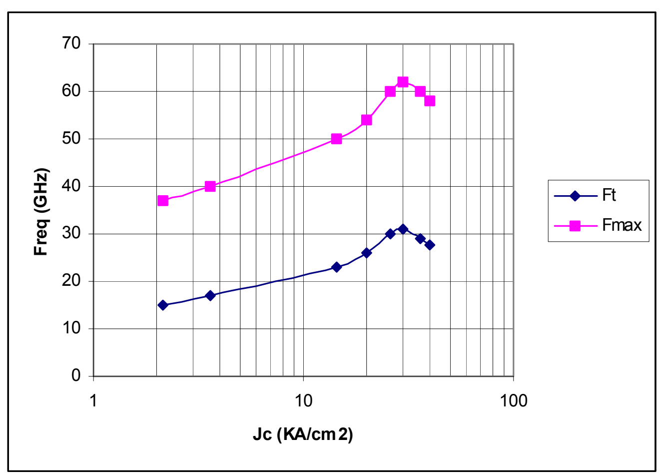



Fig. 4. Ft and Fmax versus collector current density with emitter size of 2x20 $\mu m^2$ at Vc of 3V.

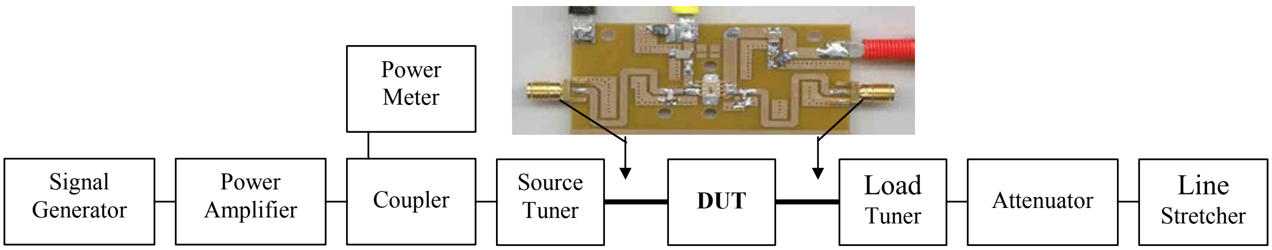



Fig. 5. Load VSWR mismatch test system setup with picture of evaluation board.

Table 3. Summary of device survivability at various test conditions

| $V_{CC}$ (V) | VSWR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 : 1 | | 10 : 1 | | 16 : 1 | | 25 : 1 | |
| Device | 3.5 | 5.0 | 3.5 | 5.0 | 3.5 | 5.0 | 3.5 | 5.0 |
| A | P | P | P | P | P | P | P | P |
| B | P | P | P | P | P | P | P | F |

POWER AND RUGGEDNESS PERFORMANCES

The device power performance was measured on a Maury load pull system. DUT was partially matched on an evaluation board with source and load tuners to get optimal match. Additional load attenuator and sliding short were used for ruggedness test as shown in Fig. 5. All the following reported data were taken at the evaluation board level without correction for matching circuitry loss. So the power performance represents closely what one would expect of a fully matched PA. The power performances of Device A and B are listed in Table 1. Device A and B have similar power performance with typical 36 dBm output power, 18 dB linear gain and 64% PAE at 900 MHz which are excellent for GSM power amplifier. The power performance of Device A was also evaluated at 1800 MHz with typical 35 dBm output power, 15 dB linear gain and 60% PAE, which meets DCS/PCS requirements also.

VSWR's of 7:1, 10:1, 16:1 and 25:1 were used during ruggedness test in CW mode at all 360°-phase rotation and at Vc of 3.5 and 5V. A constant input power of ~ 23 dBm was applied during VSWR testing at which output power was ~35.5 dBm at load match condition. The pass/fail criterion was defined as either 20% change of quiescent current or 5% degradation of power performance (either Pout, PAE or gain).

Fig. 6 shows the collector current with different phase angles at 25:1 VSWR and Vc of 3.5 and 5V for Device A. With severe mismatch condition at 5V Vc and phase angle of 90°, collector current reaches 2.2A which is equivalent to 11W DC power. Fig. 7 shows Device A's power performance before and after ruggedness test at 25:1 VSWR and 5V Vc. There was no performance degradation after the test.

Device survivability for Device A and B at different test conditions is summarized in Table 3. Device A survived 25:1 VSWR at 5V Vc and Device B survived 25:1 VSWR at 3.5V Vc . Because the die size of Device B is smaller than that of Device A, Device B is a little bit hotter, which resulted in its less ruggedness than Device A. Nevertheless, Device B survived 16:1 VSWR at 5V Vc, which is still good enough to meet GSM PA's ruggedness requirement

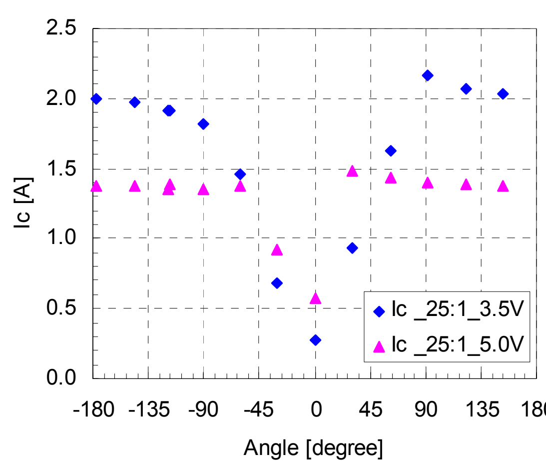



Fig. 6. The variation of DC collector current at phase rotation during ruggedness test for device A at 25:1 VSWR and 3 and 5V Vc.

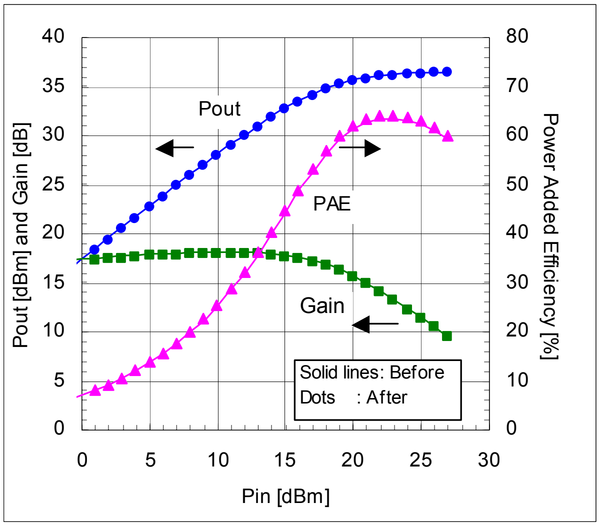



Fig. 7. RF power performance before and after ruggedness test at 25:1 VSWR of 25:1 and 5V Vc.

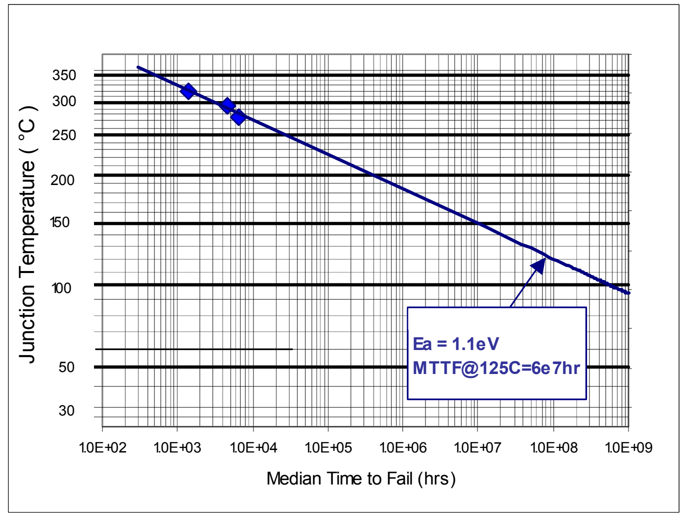



Fig. 8. Ahrrenius plot for high ruggedness HBT process with activation energy of 1.1eV and projected MTTF of $6x10^7$ hours at Tj of 125 °C

## DEVICE RELIABILITY

Three-temperature accelerated life tests on the high ruggedness devices have been conducted at Tj's of 320°C, 295°C, and 275°C with 10 devices in each group. Devices were stressed at Vc of 3.6V and Jc of $25KA/cm^2$. An Ahrrenius plot is shown in Fig. 8. The projected MTTF is $6x10^7$ hours at Tj of 125 °C with activation energy of 1.1 eV, which is sufficient to meet the reliability requirement for all wireless applications.

## CONCLUSIONS

In conclusion, we have improved InGaP/GaAs HBT's ruggedness without sacrificing its power performance. HBTs survived 25:1 VSWR at 5V Vc . To our knowledge, this is the highest ruggedness achieved for a 4W InGaP/GaAs HBT. Very good power performance was also achieved at both 900 and 1800 MHz. Excellent reliability can meet all wireless application requirements. This device is excellent candidate for GSM/DCS/PCS PA applications and it is in volume production at GCS.

## ACKNOWLEDGEMENT


The authors wish to acknowledge the assistance and support of GCS manufacture team.


## REFERENCES


[1] R. Hattori, et al. "Manufacturing technology of InGaP HBT power amplifiers for cellular phone applications," 2002 GaAs Mantech Digest, pp.241-244, April 2002.

[2] T. Niwa, T. Ishigaki, H. Shimawaki, and Y. Nashimoto, "A composite-collector InGaP/GaAs HBT with high reggedness for GSM power amplifiers," 2003 IEEE MTT-S Digest, pp. 711-714.

[3] M. Pfost, V. Kubrak, and P. Zwicknagl, "Optimization of the collector profile of InGaP/GaAs HBTs for increased robustness," 2003 IEEE GaAs Digest, pp.115-118.


## RCRONYMS

HBT: Hetero-junction bipolar transistor
VSWR: voltage standing wave ratio
PA: Power amplifier
Pout : Output power
PAE: Power added efficiency
MMIC: Monolithic microwave integrated circuit
Tj: Junction temperature
MTTF: Medium time to failure
Jc and Ic: Collector current density and collector current, respectively
Vc: Collector voltage