RF Power characteristics of SiGe Heterojunction Bipolar Transistor with High Breakdown Voltage structures

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Abstract —•• **The collector profile dependences of RF Power characteristics of SiGe Heterojunction Bipolar Transistor (HBT) have been studied. A selectively Ion Implanted collector (SIC) structure with a thick and lightly doped collector layer showed good RF power characteristics including the ADJACENT-CHANNEL-POWER-RATIO (ACPR) characteristics for middle class power around output Power of 16dBm while maintaining BV_{CEO} over 5V. The maximum BV_{CEO} of 9V was obtained using the same process only by removing the SIC structure. Both structures are available to fabrication of multi-stage RF power amplifier on to one chip by single process.**

I. INTRODUCTION

Recently, there has been increasing applications of SiGe based Bi-CMOS to RF analog ICs in the cellular phones and in the wireless local area network systems, commercially. SiGe has the advantages of its high frequency characteristics over Si and higher potential of functional integration over GaAs. Moreover, process stability based on large size wafer Si LSI process technologies results in high yield, and offers lower chip costs. SiGe HBTs have also attracted much attention for RF Power application because of their good microwave power performance, which becomes almost compatible with those of HBTs made of compound materials. [1]- [4] For the RF power transistors used in the Power Amplifiers (PA) of cellular phones, generally over 1W output power drivability is needed. So higher Breakdown voltage is required for the power transistor. Usually, PA chip consists of multi-stage transistors to obtain the required high gain. In PA chip, device structure is mainly dominated and limited by breakdown voltage of the final stage transistor needed for high power operations.

Higher breakdown voltage is needed for HBT of the final stage than those of driver stage HBT, although the both Transistors are fabricated on the chip by the same process.

In this work, we studied the Breakdown voltage, mainly collector structure dependences of RF power characteristics of SiGe HBTs, especially approximately middle class power characteristics of about output power of 16dBm.

II. EXPERIMENTALS

NPN SiGe Heterojunction Power Transistors have been fabricated using 0.25• m SiGe Bi-CMOS based Process Technologies. The base structure consists of graded SiGe epitaxial layer with maximum germanium (Ge) contents of 15%. The thickness of the collector Si epitaxial layer, the collector doping level and their profiles were varied. The thickness of the Si collector epitaxial layer was 0.55• m (thin collector) and 0.75 • •m (thick collector). The resistively of the Si epitaxial layer was fixed at 1• •cm. For 0.75• m thickness devices both with-SIC and without -SIC devices were fabricated. In the SIC structure, the collector layer was slightly doped with carrier concentration of 1e17cm^{-3} . For 0.55• m devices only the without-SIC structure was used, because of the relatively low breakdown voltage about 3V with the SIC structure, which is not suitable for power applications. The structures of the samples were shown in TABLE• :

• : RESULTS AND DISCUSSIONS

A. DC characteristics

The collector breakdown voltages of samples used in this experiment were estimated. The calculated collector structures versus open base collector-emitter breakdown•• voltage (BV_{CEO}) and the base collector break down voltage (BV_{CBO}) were shown in Fig.1 and Fig. 2.

These results show that the maximum BV_{CEO} of the 0.55 • m thick collector structure even without SIC would reach only 7V or less. This estimation is indeed confirmed by experimental as listed on Table• : We found that BV_{CEO} for the 0.55• m thick collector without SIC and for the 0.75• m thick collector with-SIC were 6.7V and 8.9V, respectively. These results showed good agreements with calculated values.

The hFE of these HBTs were about 150 for the 0.75• m collector structures while those of the 0.55• m collector structures without-SIC were about 100 .

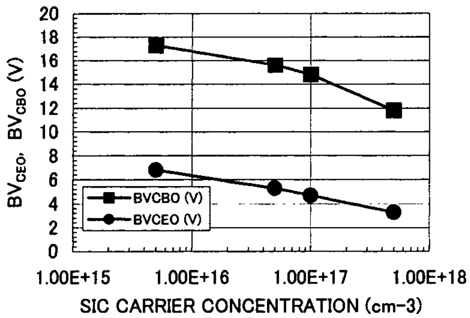

Fig1.• • Calculated Collector carrier concentrations dependence on Breakdown Voltage of HBT with collector laver thickness of 0.55• m.

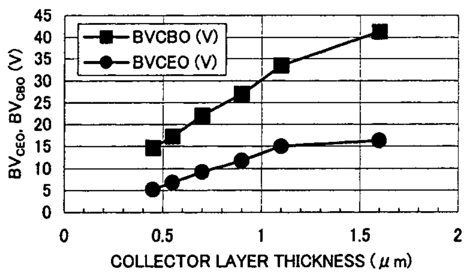

Fig.2.• • Calculated Collector layer thickness dependence on Breakdown Voltage of HBT without - SIC structures.

TABLE• •

SUMMARY OF DC AND RF CHARACTERISTICS OF HBTs.

Collector layer• • thickness (• m)	THIN 0.55	THICK 0.75	THICK 0.75
Collector doping	Without SIC	SIC	Without SIC
ft (GHz)	14	18.5	12.8
fmax (GHz)	15.7	19	15.8
hFE	104	140	150
BV_{CEO} (V)	6.7	5.3	8.9
BV_{CBO} (V)	14.9	17.1	21.6

B. RF characteristics

Small signal RF characteristics by on wafer S-parameter measurements of small size HBTs have been evaluated. The emitter size of measured device were 0.65• m x 20• • m x 2 fingers.

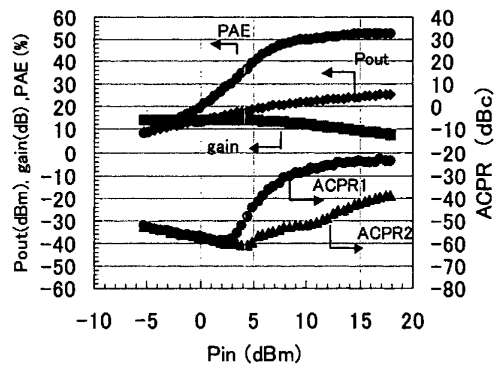

Fig.3 Output power, power gain, power-added-efficiency and ACPR versus input power for the HBT with 0.75 • m collector layer thickness and slightly doping SIC structure at 1.95 GHz, V_{CE} =3.5V.

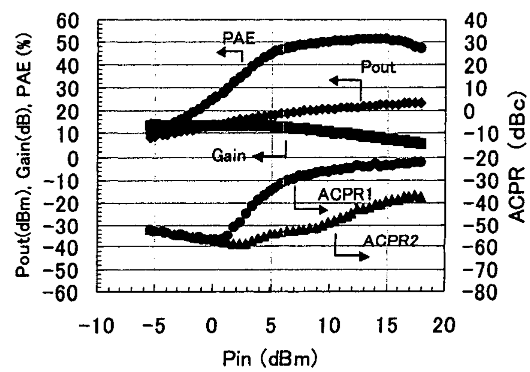

Fig.4. Output power, power gain, power-added-efficiency and ACPR versus input power for the HBT with 0.75 • m collector layer thickness and slightly doping SIC structure• • at 1.95 GHz, V_{CE} =2.7V.

The Power characteristics of HBTs have been measured by the load pull method at the frequency of 1.95 GHz.

Modulated Signals of W-CDMA handsets were used to evaluate intermodulation characteristics.

The emitter size of the HBTs used for RF power measurements were 520• m^2• 0.65• m x 20• m x 40 fingers.• •

In the load pull measurements, output power was fixed at 16dBm, this output power is comparable with that of the 1st stage transistor used in the 2-stage amplifier for the W-CDMA cellular handsets. The adjacent-channel-power-ratio (ACPR) optimized output impedance matching was chosen for the power characteristics measurements.

The measurements were also made for two different collector supply voltages of V_{CE} = 2.7V and 3.5V.

Fig.3 shows the Output power, power gain, power-added-efficiency• PAE• •and ACPR characteristics of the HBT with 0.75 • m collector layer thickness and slightly doped SIC structure at 1.95 GHz with V_{CE} =3.5V.

RF Power measurement results were summarized in Table• • The sample with thick collector layer and SIC showed lower BVceo of 5.3V, however, 1dB gain compression point of P1dB, PAE, and the ACPR were much better than those of sample without SIC, while gain value were almost the same as those of the former structures.

With lower voltage operation of thick collector HBTs, degradation of ACPR in samples without SIC is more sever than those with SIC. The minimum 5MHz offset ACPR1@16dBm is limited to –39dBc for without the SIC structures, while –48dBc was obtained for slightly doped SIC structure at V_{CE} of 2.7V as shown in Fig.4. The maximum power of almost 30dBm was also confirmed for the larger emitter size HBTs without SIC thick collector structure.

HBTs for the multi-stage power amplifier use, thicker collector layer with light doping showed better RF power performance and can be applicable to the driver stage. By using the combination of these two structures, the driver stage HBT and final stage HBT with high breakdown voltage can be fabricated on one chip by single process.

TABLE• •

SUMMARY OF RF POWER CHARACTERISTICS OF HBTs.

Collector layer• • thickness (• m)	THIN 0.55	THICK 0.75	THICK 0.75
Collector doping	Without SIC	SIC	Without SIC
P1dB (dBm)	23.3	24.1	20.4
Gain (dB)	13.9	14	13.9
PAE (%)	26.3	27.6	21.3
ACPR1 (dBc)	-58.3	-58	-48
ACPR2 (dBc)	-59.5	-59	-58

• • CONCLUSION

In conclusion, RF power characteristics of high breakdown voltage SiGe Heterojunction Bipolar Transistors have been studied. The collector breakdown voltage BV_{CEO} of over 9V has been achieved by adopting thick collector layer without SIC. Almost the same RF power performance was obtained for slightly doped SIC structure with thick collector as thinner collector HBT without SIC for the lower output power level around 16dBm. Both of the driver stage (BV_{CEO}=5V) HBT and the final stage (BV_{CEO}=9V) HBT structures can be fabricated on one chip by one fabrication process.

Hence, the combinations of these HBT structures are promising for high power one chip multi-stage power Amplifiers.

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