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A Multi-Finger $Si_{1-x}Ge_x/Si$ Heterojunction Bipolar Transistor for Wireless Power Amplifier Applications*

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Abstract: A large area multi-finger configuration power SiGe HBT device (with an emitter area of about $880\mu m^2$) was fabricated with $2\mu m$ double-mesa technology. The maximum DC current gain β is 214. The BV_{CEO} is up to 10V, and the BV_{CBO} is up to 16V with a collector doping concentration of $1\times10^{17}cm^{-3}$ and collector thickness of 400nm. The device exhibits a maximum oscillation frequency f_{max} of 19.3GHz and a cut-off frequency f_T of 18.0GHz at a DC bias point of $I_C=30mA$ and $V_{CE}=3V$. MSG (maximum stable gain) is 24.5dB, and U (Mason unilateral gain) is 26.6dB at 1GHz. Due to the novel distribution layout, no notable current gain fall-off or thermal effects are observed in the *I-V* characteristics at high collector current.

Key words: SiGe; HBT; power; double-mesa technology; multi-finger
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1 Introduction

Power amplifiers (PA) are key components in the wireless communications industry. The conventional low-cost silicon BJTs (bipolar junction transistors), in which the frequency response is limited by intrinsic Si material properties, are not suitable for microwave or RF applications. GaAs HBTs have dominated in such applications. However, the high-cost, low thermal conductivity and poor mechanical strength of these materials have made them slightly inaccessible for high-level integration. Bandgap-engineered SiGe HBT is an emerging alternative for microwave and RF applications due to the advantages of low cost, superior thermal conductivity and compatibility with Si CMOS technology. The SiGe HBT based RFIC is one of the most cost-effective technologies for high frequency wireless applications today.

SiGe HBT MMIC power amplifiers have received much attention as a potential candidate for wireless communication applications. The challenge faced by SiGe-based MMIC PA technologies is to provide power HBTs that have sufficient high-voltage immunity without compromising device performance[1]. Some efforts on the microwave power application of SiGe-based HBTs have been reported[2~7]. In Ref. [7] a 30 finger microwave power SiGe HBT with 23V BV_{CBO} and 7GHz f_T were reported. To acquire a large BV_{CBO}, the collector thickness was grown to $2\mu m$, for which it is difficult to acquire a high quality heterostructure and good frequency performance. To acquire high power and frequency performance at the same time, the heterostructure and the device layout have to be well designed with considerations of thermal effects, breakdown voltage, and output power. In this paper we describe a very simple technology of SiGe HBT fabrication, in which only 5 masks are needed. With the $2\mu m$ double-mesa technology, multi-finger (5-cell, 10-finger) configuration power SiGe HBTs have been fabricated. The BV_{CEO} is up to 10V, and the BV_{CBO} is up to 16V with a collector doping concentration of $1\times10^{17}cm^{-3}$ and collector thickness of 400nm.

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2 Device structure design and fabrication process

The heterostructure, as shown in Fig. 1, was grown on low-resistivity ($\rho = 2.4 \times 10^{-3}\ \Omega \cdot cm$) 50mm Si wafer in one step by UHV/CVD. The high doping substrate is directly used as sub-collector to achieve a smaller collector access/spreading resistance. A high breakdown voltage is preferred for power HBT design for wireless power amplifier applications. It can be obtained by designing a thick and lightly doped collector layer. As a consequence, the doping concentration is selected to be $1 \times 10^{17} cm^{-3}$ and the thickness is 400nm. The maximum boron concentration of $2 \times 10^{19} cm^{-3}$ in the base layer ensures a low base access/spreading resistance. The doping concentration in the emitter cap layer is also $2 \times 10^{19} cm^{-3}$ so as to reduce emitter contact resistance.

Emitter cap	Si	n^+	P	$2 \times 10^{19} cm^{-3}$	100nm
Emitter	Si	n	P	$3 \times 10^{17} cm^{-3}$	100nm
Spacer	$Si_{1-x}Ge_x$ ($0.20 \leqslant x \leqslant 0.25$)	i			10nm
Base	$Si_{1-x}Ge_x$ ($0.20 \leqslant x \leqslant 0.25$)	p	B	$2 \times 10^{19} cm^{-3}$	25nm
Spacer	$Si_{1-x}Ge_x$ ($0.20 \leqslant x \leqslant 0.25$)	i			10nm
Collector	Si	n^-	P	$1 \times 10^{17} cm^{-3}$	400nm
Substrate	Si	n^+		$\rho = 2.4 \times 10^{-3}\ \Omega \cdot cm$	350μm

Fig. 1 Specifications of epitaxial layer of SiGe/Si HBT

In order to obtain good current handling capability, a multiple finger configuration design for the emitter and base contacts is often chosen. All the emitter fingers can be divided into several subcells, in each of which several fingers with narrow finger spacing are bound together. This configuration can not only reduce thermal effects without increasing C_{BC} (B-C junction capacitance), but also decrease collector spreading resistance.

Double mesa-type HBTs were fabricated with standard liftoff and etching techniques. The fabrication process is described in Ref. [8] in detail. Figure 2 shows the micrograph of a finished five-cell ten-fingers common-emitter HBT. The emitter finger width is 1.6μm and the length is 30μm. The space between the fingers is 2μm. Figure 3 shows a schematic cross-section of a two-cell of SiGe/Si DHBT. The space between the base mesa and the collector electrode is 3μm. The space between the emitter mesa and the base electrode is 2μm.

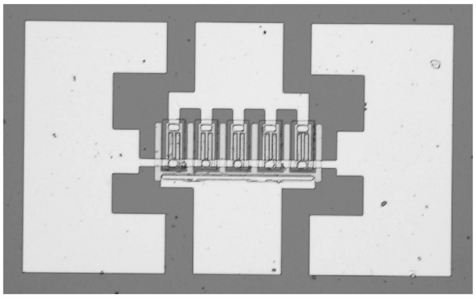

Fig. 2 Micrograph of a five-cell

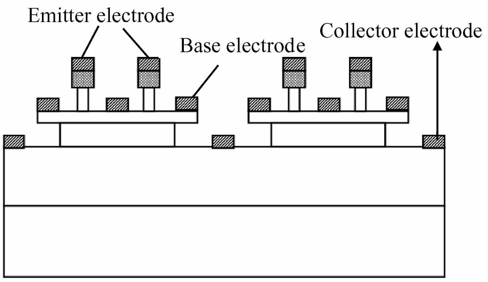

Fig. 3 Schematic cross-section of a two-cell of SiGe/Si HBT

3 Results and discussion

The DC characteristics of the devices were measured with an HP4155A semiconductor parameter analyzer. Figure 4 shows the current gain as a function of the collector current. The *I-V* characteristic of a 10-finger HBT is shown in Fig. 5. It exhibits a maximum DC current gain β of 214. The measured C-E junction breakdown voltage (BV_{CEO}) is over 9V. The measured C-B junction breakdown voltage (BV_{CBO}) is about 16V with collector thickness designed as 400nm. The offset voltage of the common emitter configuration is about 0.2V. The offset voltage is small and is an advantage in terms of the power added efficiency (PAE). The knee (saturation) voltage of the CE configuration is 3.2V. The knee voltage is slightly large, which is caused by the large collector access resistance from the Ohmic contact of the collector electrode and layout design (3μm separation between base mesa and collector metal). With the increasing of the collector current, a slight current gain fall-off is found when I_C is larger than 50mA. No notable thermal effects were observed in the I-V characteristics mainly because of the novel distributed layout.

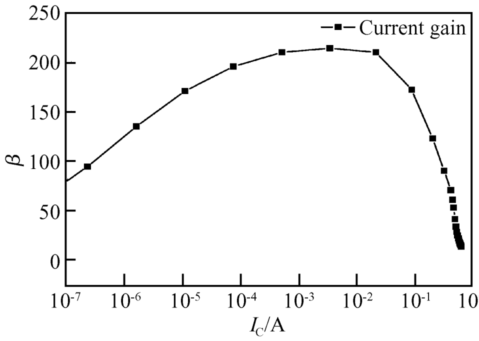

Fig. 4 Current gain as a function of collector currents

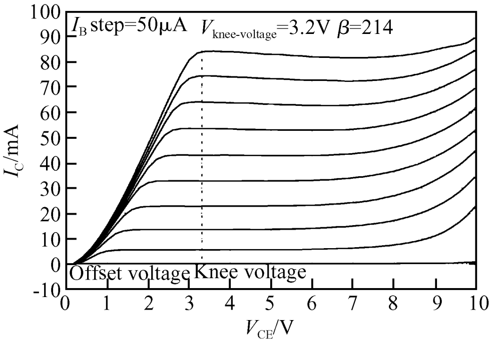

Fig. 5 I-V characteristics of the SiGe/Si HBT with ten 1.6μm×30μm emitter fingers

The high base leakage current is commonly observed in double-mesa Si/SiGe HBT, which mainly arises from the noncoincidence between BE pn junction and Si/SiGe heterojunction and insufficiently passivated surface states. The Gummel plot is shown in Fig. 6, which indicates excellent interface quality and sufficiently passivated surface states.

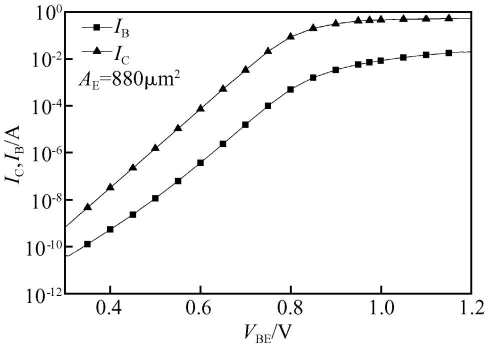

Fig. 6 Gummel plot of the SiGe/Si HBT with ten 1.6μm×30μm emitter fingers

For small signal RF characteristic, an on-wafer probing S-parameter measurement was performed using an HP8510C network analyzer. Figures 7 and 8 show the current gain $|H_{21}|$ and the unilateral power gain GU at a DC bias point of $I_C = 30$mA and $V_{CE} = 3.0$V, respectively. The device exhibits a maximum oscillation frequency $f_{\max}$ of 10.3GHz and a cut-off frequency f_T of 9.3GHz. In order to make the HBT testable, additional RF probe pads must be connected to it and they can have a significant influence on the measurement[1]. The influence of the RF probe pads from measurement data is removed, and f_T of the actual device is 18GHz and $f_{\max}$ is 19.3GHz. The maximum power gain is MSG (maximum stable gain) = 24.5dB and U (Mason unilateral gain) = 26.6dB at 1GHz.

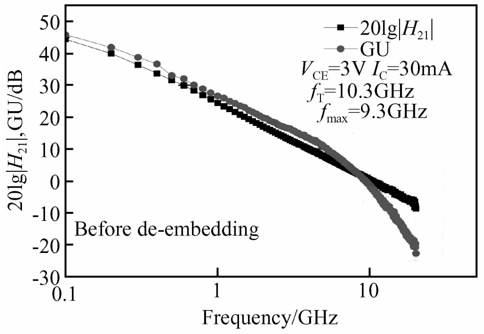

Fig. 7 Small-signal characteristics of a 10-finger SiGe/Si HBT before de-embedding

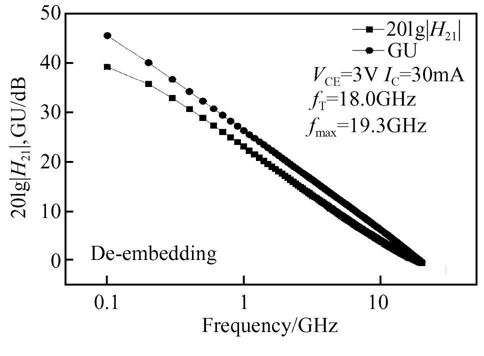

Fig. 8 Small-signal characteristics of a 10-finger SiGe/Si HBT after de-embedding

4 Conclusion

A novel distributed layout multifinger configuration power SiGe HBT device was fabricated with a very simple 2μm double-mesa technology. Through optimization of the vertical heterostructure design and layout design, the device exhibited perfect performance. The maximum DC current gain β was 214. The BV_{CEO} was up to 10V, and the BV_{CBO} was up to 16V. Though the emitter area was quite large (880μm), the device exhibited a maximum oscillation frequency f_{max} of 19.3GHz and a cut-off frequency f_T of 18.0GHz at a DC bias point of $I_C = 30$mA and $V_{CE} = 3$V. The maximum power gain is MSG (maximum stable gain) = 24.5dB and U (Mason unilateral gain) = 26.6dB at 1GHz.

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基于无线功率放大器应用的多指结构 SiGe HBT*

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摘要： 采用简单的双台面工艺制作了完全平面结构的 5 个单元、10 个发射极指大面积的 SiGe HBT. 器件表现出了良好的直流和高频特性，最大电流增益 β 为 214. BV_{CEO}为 9V，集电极掺杂浓度为 $1\times10^{17}cm^{-3}$，厚度为 400nm 时，BV_{CBO}为 16V. 在直流偏置下 $I_C = 30$mA，$V_{CE} = 3.0$V 得到 f_T 和 f_{max}分别为 18.0GHz 和 19.3GHz，1GHz 下最大稳定增益为 24.5dB，单端功率增益为 26.6dB. 器件采用了新颖的分单元结构，在大电流下没有明显的增益塌陷现象和热效应出现.

关键词： SiGe；HBT；高频；双台面工艺；多指结

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