Self-Aligned InGaP/GaAs Power HBTs with a Low Bias Voltage*

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Abstract: A self-aligned InGaP/GaAs power HBTs for L-band power amplifier with low bias voltage are described. Base emitter metal self-aligning, air-bridge, and wafer-thinning are used to improve microwave power performance. A power HBT with double size of emitter of (3μm×15μm)×12 is fabricated. When the packaged HBT operates in class AB at a collector bias of 3V, a maximum 23dBm output power with 45% power added efficiency is achieved at 2GHz. The results show that the InGaP/GaAs power HBTs have great potential in mobile communication systems operating at low bias voltage.

Key words: self-aligned; InGaP; power HBTs; low bias voltage

EEACC: 2560Z

CLC number: TN322⁺.8 **Document code**: A **Article ID**: 0253-4177(2004)08-0908-05

1 Introduction

L-band power amplifiers with single and low bias voltage are greatly required for mobile communication systems. Heterojunction bipolar transistors (HBTs) have strong potential for the application of high-power, high-efficiency microwave solid-state amplifier[1~3]. Compared with other solid-state three-terminal devices, HBTs are attractive for power amplifier application for the higher power density operation, higher breakdown voltage, higher impedance values, high efficiency, and operation with single bias supply. Moreover, the optical lithography compatible dimensions of the HBT also make it amenable to high yield, low-cost, volume production.

So far, several researches working on AlGaAs/GaAs power HBTs have very impressive results[4~6]. But due to inherent material limitations, i.e. the two semiconductors (AlGaAs and GaAs) having the same anion (As), AlGaAs/GaAs power HBTs will effectively lower the minority-carrier injection efficiency of the emitter by the existence of conduction band spike. The use of InGaP, instead of AlGaAs, will allow the improvement of minority-carrier injection efficiency and lower Vce-offset, a collector emitter offset voltage because of the difference in conduction band discontinuities at the emitter-base and base-collector junctions. In addition, extreme high etching selectivity between InGaP and GaAs will enhance process yield and result in lower base resistance without overetching the base. So, InGaP/GaAs HBTs are preferable to AlGaAs/GaAs HBTs for low-bias voltage and high power operation[7~9].

The research working on the InGaP/GaAs power HBTs in China has never been reported till

* Project supported by State Key Development Program for Basic Research of China (No. 2002CB31190), National Natural Sicence Foundation of China (No. 60146001), and National Knowledge Innovation Program of CAS.

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Received 29 December 2003, revised manuscript received 18 March 2004

now. In this paper, we present the design and fabrication of the self-aligned InGaP/GaAs power HBTs operating at low bias voltage at L-band frequency. The device exhibits good microwave power performance.

2 Design and Fabrication

The InGaP/GaAs HBTs structures are grown by MOCVD on a semi-insulating GaAs substrate with 4 inch. The thickness of collector has to be chosen by tradeoff between the collector voltage and the transit time delay. A 700nm thick collector is used in the epitaxial structure. The epitaxial structure of the InGaP/GaAs power HBT is shown in Table 1.

Table 1 Epitaxial structure of InGaP/GaAs power HBT

Layer name	Material	Doping $/cm^{-3}$	Thickness /nm
Cap layer	n^+-$In_xGa_{1-x}As(x=0.6)$	$>1\times10^{19}$	50
Cap layer	n^+-$In_xGa_{1-x}As(x=0.6\sim0)$	$>1\times10^{19}$	50
Cap layer	n^+-GaAs	5×10^{18}	120
Emitter layer	$In_xGa_{1-x}P(x=0.5)$	3×10^{17}	50
Base layer	p^+-GaAs	4×10^{19}	60
Collector	n^--GaAs	3×10^{16}	700
Subcollector	n^+-GaAs	5×10^{18}	500

A self-aligned emitter-base process is used to minimize the base series resistance and base-collector capacitor[10]. First, the emitter metal pattern is defined, evaporated, and lift-off. Then, the base is accessed through wet etching, and self-aligned base contacts are deposited on the base layer. Following the base metal evaporation, the collector is accessed through wet etching, and AuGeNi/Ag/Au for collector contact alloys. The collector contact metal is alloyed at 390℃ for 1 min. Then, the device is passivated by SiN and SiO. Finally, all emitter contacts are joined together using low parasitic air bridges. The wafer is to be thinned to 100 μm after all the front-side processes are completed. This thickness is chosen as a design compromise between low thermal resistance and low microwave loss. In order to decrease the parasitic effect and die area, we use the HBT with double emitters. And an emitter-ballasting resistor of 4Ω/finger is included to get the thermal stability. Fig. 1 is the microscope photograph of the device, the emitter size is $2\times(3\mu m\times15\mu m)\times12$.

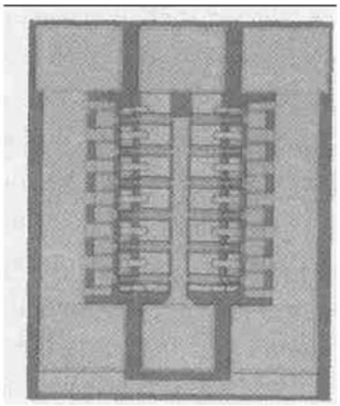

Fig. 1 Microscope photograph of power HBT The emitter size is $2\times(3\mu m\times15\mu m)\times12$.

3 Results and discussion

3.1 DC and small signal characteristics

The DC performances of the device are measured by the semiconductor curve tracer. The common emitter I-V characteristics of the InGaP/GaAs power HBT is shown in Fig. 2, where I_b = 1mA/step. Figure 2 shows the DC current gain is about 20 without the current gain collapse that means a 4Ω emitter resistance is enough to avoid current gain collapse. Figure 2 also shows that the V_{ce}-offset is about 0.3V, the knee voltage is about 0.7V at the current density of $17kA/cm^2$. And the breakdown voltage (BVceo) of the unit InGaP/GaAs HBT is 12V.

The small-signal microwave performances of the power HBT are measured with a HP8510C vector network analyzer and cascade microwave coplanar waveguide probes. Figure 3 shows the measured current gain (H_{21}) and maximum available/stable gain (G_{max}) as a function of frequency. The f_t and f_{max} of the power HBT are 38GHz and 30GHz by extrapolating the current gain and the maximum available/stable gain with a − 20dB/oct roll-off, respectively. 24.5dB, the maximum available gain, was achieved at 2GHz. After package, the small signal power performance of the device at the same bias (V_{ce}= 2V and I_c= 100mA) is measured by Agilent E8363B performance network analyzer. Figure 4 shows the variation of maximum available gain with frequency. The f_{max} of the same power HBT decreases to 11GHz. 11.5dB, the small-signal maximum available gain (G_{max}), was achieved at 2GHz. So, the process of package is crucial to the performance of the power HBT. In order to improve the performance of the packaged power HBT, decreasing the package parasitic parameter in the work frequency and decreasing the emitter series inductance are very important. The Via hole process can decrease the emitter serious inductance effectively.

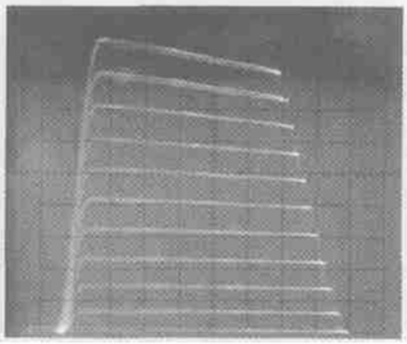

Fig. 2 Common emitter I-V characteristics of a 2×(3μm × 15μm) × 12 HBT I_b = 1mA/step, I_c = 20mA, V_{ce}= 0.5V/step

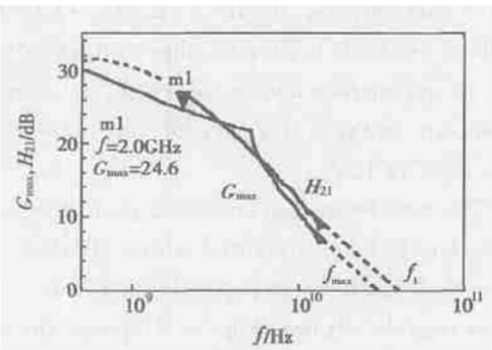

Fig. 3 Measured current gain, maximum available/stable gain of the power HBT as a function of frequency V_{ce}= 24V

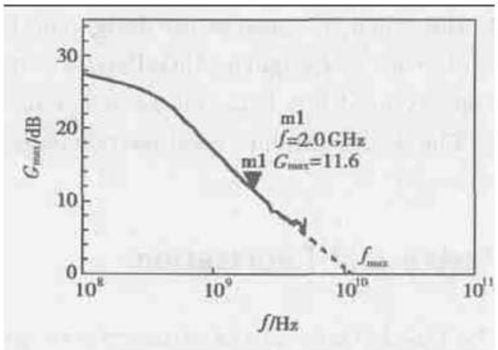

Fig. 4 Measured maximum available gain of the packaged power HBT as a function of frequency V_{ce} = 2V, I_c= 100mA

3.2 Microwave power characteristics

The CW power characteristics of 2×(3μm × 15μm) ×12 HBT device at 2GHz are measured with variable sources and load impedance. The packaged power HBT is mounted on Au carriers, and then bonded to microstrip lines on thick alumina substrates mounted on a brass test fixture. The harmonics are not tuned in the matching circuits. Figure 5 shows the measured output power (P_{out})、power gain (G_P) and power-added efficiency (PAE) at 3V of collector voltage under class AB operation. The load is tuned to a maximum power. When the packaged HBT operates at 3V of collector bias and collector current of 200mA, a 23dBm maximum output power with 45% power added efficiency and 7dB power gain are achieved at 2GHz. The output power at 1dB gain compression (P_{1dB}) is 21dBm with 9.5dB of linearity power gain.

Figure 6 is a typical output spectrum acquired from the HP8563E spectrum analyzer, the frequency range is 0.5~ 3.5GHz. The RF input signal frequency is 2GHz. There is an output spectrum at 2GHz. No parasitic clutter is found.

4 Conclusion

In this paper, a high performance 2×(3μm × 15μm) ×12 self-aligned InGaP/GaAs power HBTs with a low bias voltage at L-band frequency is demonstrated. The measurement results of the device indicate that a maximum 23dBm power output with a linearity power gain of 9.5dB and a 45% maximum power added efficiency with 3V bias under class AB operation are achieved. Theses results show that InGaP/GaAs power HBTs are suitable for mobile communication systems.

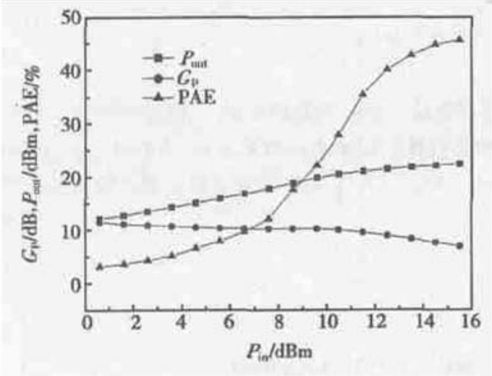

Fig. 5 Measured CW output power, PAE, gain(G_p) of a 2×(3μm×15μm)×12 HBT with V_{ce} of 3V

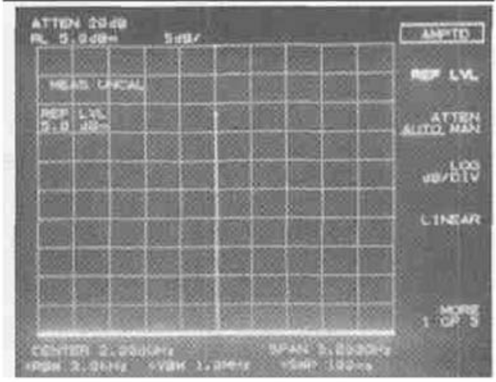

Fig. 6 Output spectrum of the 2×(3μm×15μm)×12 HBT with V_{ce} of 3V

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低偏置电压工作的自对准 InGaP/GaAs 功率异质结双极晶体管*

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摘要: 介绍L波段、低偏置电压下工作的自对准InGaP/GaAs功率异质结双极晶体管的研制. 在晶体管制作过程中采用了发射极-基极金属自对准、空气桥以及减薄等工艺改善其功率特性. 功率测试结果显示: 当器件工作在AB类, 工作频率为2GHz, 集电极偏置电压仅为3V时, 尺寸为2×(3μm×15μm)×12的功率管获得了最大输出功率为23dBm, 最大功率附加效率为45%, 线性增益为10dB的良好性能.

关键词: 自对准; InGaP; 功率双异质结晶体管; 低偏置电压

EEACC: 2560Z

中图分类号: TN322⁺.8 **文献标识码**: A **文章编号**: 0253-4177(2004)08-0908-05

* 国家重点基础研究发展规划(批准号: 2002CB311902), 国家自然科学基金(批准号: 60146001)及中国科学院知识创新工程资助项目

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2003-12-29 收到, 2004-03-18 定稿