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Performance of an InP DHBT Grown by MBE

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Abstract: We report the performance of the first self-aligned InP/InGaAs double heterojunction bipolar transistor (DHBT) produced in China. The device has a 2μm ×12μm U-shaped emitter area and demonstrates a peak common-emitter DC current gain of over 300, an offset voltage of 0.16V, a knee voltage of 0.6V, and an open-base breakdown voltage of about 6V. The HBT exhibits good microwave performance with a current gain cutoff frequency of 80GHz and a maximum oscillation frequency of 40GHz. These results indicate that this InP/InGaAs DHBT is suitable for low-voltage, low-power, and high-frequency applications.

Key words: MBE; Be-doped InGaAs base; InP; double heterojunction bipolar transistor
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1 Introduction

Aggressively scaled InP/InGaAs-based single heterojunction bipolar transistors (SHBTs) have demonstrated good microwave characteristics, but their high cutoff frequencies are achieved at the expense of breakdown voltage because of the narrow gap of the InGaAs collector[1~4]. Wide-bandgap $Al_{0.48}In_{0.52}As$ or InP collector layers in double heterojunction bipolar transistors (DHBTs) can improve the breakdown voltage, while it is difficult to design the collector structure because of current blocking that results from the positive conduction band discontinuity between the $In_{0.53}Ga_{0.47}As$ and $Al_{0.48}In_{0.52}As$ or InP. For an InP collector, a blocking barrier of about 0.25eV must be overcome between the base and the collector. Current blocking raises the saturation voltage and increases carrier storage and recombination in the base layer, so various doping and/or compositional grading schemes have been implemented to alleviate blocking effects at the B/C heterojunction (Fig. 1)[5~13].

In this paper, we develop a novel structure for an InP/InGaAs DHBT with a 3nm-thick InP layer doped with silicon to a concentration of 3×10^{19} cm^{-3} to minimize the current blocking effect at the base-collector interface. We have successfully fabricated a 2μm ×12μm self-aligned InP/InGaAs DHBT and demonstrated its good device performance.

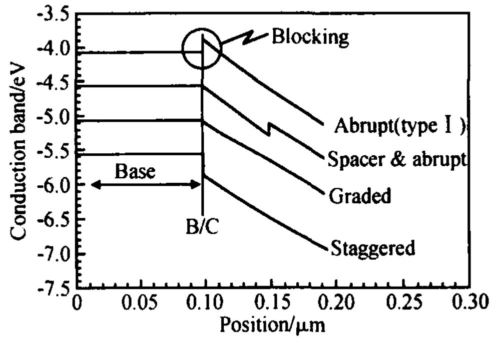

Fig. 1 Conduction band diagrams for common approaches to overcoming the collector current blocking at the B/C heterojunction of DHBTs

2 Device structure and fabrication

The epitaxial layer materials of our lattice-matched InP/InGaAs DHBT are grown on a 50mm semi-insulating InP (100) substrate by a V90 gas-source molecular beam epitaxy (GSMBE) system at the Shanghai Institute of Microsystem and Information Technology, and the devices are fabrica-

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Group-V arsenic and phosphorus beams are obtained by the thermal cracking of arsine (AsH_3) and phosphine (PH_3) at high temperatures. 7N-purity elemental gallium (Ga) and indium (In) are used as the group-III sources, while silicon (Si) and beryllium (Be) for the n- and p-type dopants, respectively[14]. The device structure is shown in Table 1. This is a novel structure for InP/InGaAs DHBTs. In particular, a 5nm undoped $Ga_{0.47}In_{0.53}As$ layer between the emitter and base layers is used to prevent the p-type Be-dopant from diffusing into the emitter layer. A 3nm-thick InP layer doped with silicon to $3\times10^{19}cm^{-3}$ is used to minimize the barrier spike between the base and the collector. The highly beryllium-doped $Ga_{0.47}In_{0.53}As$ base layer with a concentration of $3\times10^{19}cm^{-3}$ reduces the base resistance and improves the microwave performance.

Table 1　Epitaxial structure of InP/InGaAs DHBT

Layer	Material	Thickness/nm	Doping/cm^{-3}
Emitter contact	$In_{0.53}Ga_{0.47}As$	200	Si: 1×10^{19}
Emitter cap	InP	50	Si: 3×10^{19}
Emitter	InP	70	Si: 3×10^{17}
Spacer	$In_{0.53}Ga_{0.47}As$	5	-
Base	$In_{0.53}Ga_{0.47}As$	50	Be: 3×10^{19}
Spacer	$In_{0.53}Ga_{0.47}As$	5	-
Collector	InP	3	Si: 3×10^{19}
	InP	300	Si: 2×10^{16}
Subcollector	$In_{0.53}Ga_{0.47}As$	500	Si: 1×10^{19}
InP (100) SI substrate			

The InP/InGaAs DHBT devices are fabricated with a standard triple-mesa isolation process. First, the emitter metal Ti/Au is formed by e-beam evaporation and lift off. The InGaAs emitter contact layer and the InP emitter layer are etched by $H_2O_2/H_3PO_4/H_2O$ and HCl : H_3PO_4 solutions, respectively. Second, Ti/Pt/Au layers are used for the base ohmic contact metals. The base-collector mesa etch and isolation etch are accomplished by selective wet etching. Third, the collector contact metal Ti/Au is evaporated on the surface of the InGaAs subcollector; and finally, coplanar pads are connected to the emitter, base, and collector metals by air-bridge technology.

3　Results and discussion

3.1　DC characteristics

The DC characteristics of the HBT are measured with an HP4155A parameter analyzer. Figure 2 shows the common-emitter DC characteristics of the InP/InGaAs DHBT with a 2μm × 12μm emitter area. The peak current gain β is over 300. The InP/InGaAs DHBT clearly shows a low offset voltage V_{offset} of approximately 0.16V. The knee voltage V_{knee} is about 0.6V at $I_c = 11mA$ and is affected by the parasitic collector resistance. The breakdown voltage BV_{ceo} is about 6V at a reverse current of 10μA (Fig. 3). These results indicate that these InP/InGaAs DHBTs are suitable for low-voltage, low-power applications. Calculated from the Gummel plot of the InP/InGaAs DHBT with a 2μm × 12μm emitter area (Fig. 4), the ideality factors for the base and collector current are $n_b = 1.17$ and $n_c = 1.12$, respectively. The near-ideal results show good BE and BC junction characteristics for an InP/InGaAs DHBT.

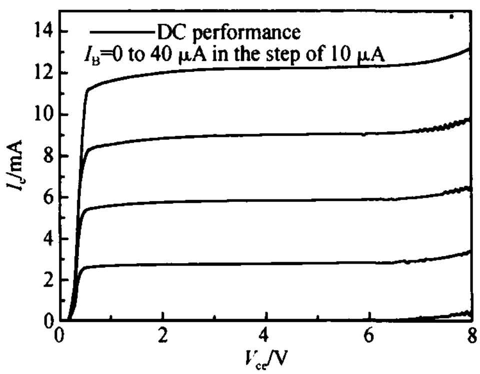

Fig. 2　Common-emitter I-V characteristics of InP/InGaAs DHBT with 2μm × 12μm emitter area

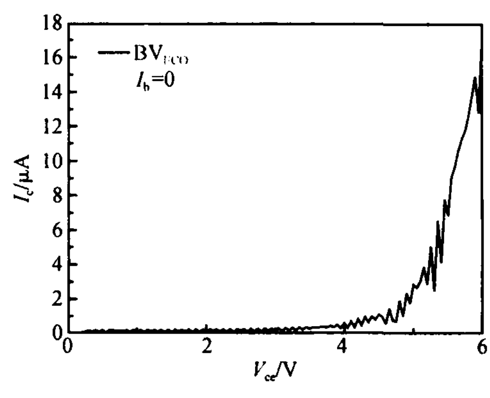

Fig. 3　Breakdown characteristics of InP/InGaAs DHBT with 2μm × 12μm emitter area

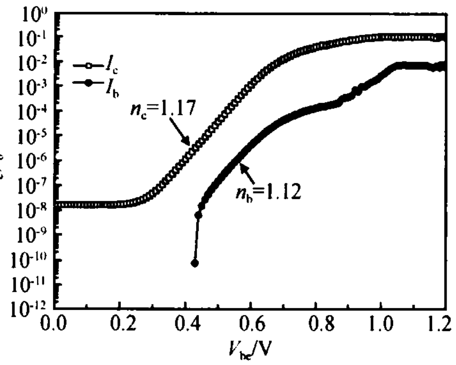

Fig. 4 Gummel plot of InP/ InGaAs DHBT with 2μm ×12μm emitter area

3.2 RF performance

The small signal S parameters of the InP/ InGaAs DHBT are measured on-wafer with an HP8510C network analyzer. The characteristics of the current gain h_{21} and maximum available gain (MAG) of the device are shown in Fig. 5. The current gain cutoff frequency f_T and the maximum oscillation frequency f_{max} can be extrapolated by extending the curves at the - 20dB/ decade line. From Fig. 5, f_T and f_{max} of the InP/ InGaAs DHBT with a 2μm ×12μm emitter area are found to be 80GHz and 40GHz, respectively, at a measured point of V_{ce} = 2.5V and I_c = 18mA. Because the base contact metal is fabricated on the 5nm undoped $Ga_{0.47}In_{0.53}As$ spacer layer instead of the 50nm Be-doped $Ga_{0.47}In_{0.53}As$ base layer surface, resulting in the high base contact resistance. The value of the maximum oscillation frequency f_{max} is below the current gain cutoff frequency f_t. Minimizing the base resistance or base-collector junction capacitance C_{bc} can improve the high frequency performance. We believe that scaling down the device or decreasing the thickness of the epilayers will greatly enhance the performance of the DHBTs.

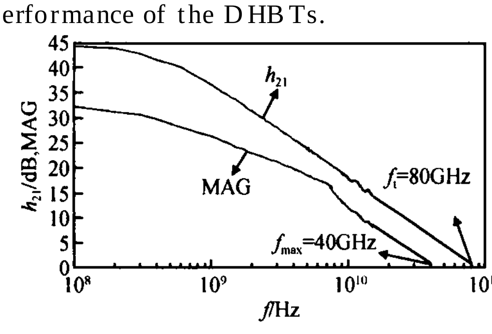

Fig. 5 High-frequency performance of 2μm ×12μm InP/ InGaAs DHBT at V_{ce} = 2.5V and I_c = 18mA

4 Conclusion

We have developed a novel InP/ InGaAs DHBT without current blocking effect between the base and the collector for the first time in China. The 2μm ×12μm self-aligned InP/ InGaAs DHBT device shows good DC characteristics of V_{offset} ≈ 0.16V, V_{knee} ≈ 0.6V, and BV_{ceo} ≈ 6V. The fabricated devices demonstrate good microwave performance with f_t = 80GHz and f_{max} = 40GHz, respectively. The above-mentioned results indicate that the devices have great potential in low-voltage, low-power, and high-frequency applications. Optimizing the material growth, device structure, and manufacturing process of the InP/ InGaAs DHBT could yield much higher performance in the future.

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MBE 生长的 InP DHBT 的性能

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摘要: 报道了一种自对准 InP/InGaAs 双异质结双极晶体管的器件性能. 成功制作了 U 型发射极尺寸为 2μm × 12μm 的器件, 其峰值共射直流增益超过 300, 残余电压约为 0.16V, 膝点电压仅为 0.6V, 而击穿电压约为 6V. 器件的截至频率达到 80GHz, 最大震荡频率为 40GHz. 这些特性使此类器件更适合于低压、低功耗及高频方面的应用.

关键词: MBE; Be 掺杂 InGaAs 基区; 磷化铟; 双异质结双极晶体管
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