第 29 卷　第 3 期
2008 年 3 月

半 导 体 学 报
JOURNAL OF SEMICONDUCTORS

Vol.29　No.3
Mar.,2008

Ultra High-Speed InP/InGaAs SHBTs with f_t of 210GHz

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Abstract: Polyimide passivation and planarization process techniques for high speed InP/InGaAs single heterojunction bipolar transistors (SHBTS) are developed. A maximum extrapolated f_t of 210GHz is achieved for the SHBT with 1.4μm × 15μm emitter area at V_{CE} = 1.1V and I_C = 33.5mA. This device is suitable for high speed and low power applications, such as ultra high speed mixed signal circuits and optoelectronic communication ICs.

Key words: InP; HBT; polyimide; planarization
EEACC: 2560J
CLC number: TN385　　**Document code**: A　　**Article ID**: 0253-4177(2008)03-0414-04

1 Introduction

InP HBTs have inherent material advantages such as high electron saturation velocity and high electron mobility, making them suitable for ultra high speed mixed signal circuits and optoelectronic communication ICs[1]. Although InP-based double heterojunction bipolar transistors (DHBTS) have higher breakdown voltage than single heterojunction bipolar transistors (SHBTS), InP-based DHBTs require a complicated epitaxy layer structure to overcome the current blocking effect at the base-collector junction[2]. In this paper, an InP-based SHBT with a simple epitaxy layer structure using polyimide passivation and planarization process techniques is reported. The device shows excellent DC and RF characteristics which is suitable for high speed and low power optoelectronic applications[3].

We have successfully fabricated InP-based SHBTs with f_t of 178GHz[4] using a base μ-bridge and an emitter air-bridge process technology. But the base μ-bridge and emitter air-bridge process technique has shortcomings that are difficult to overcome. First, because the μ-bridge is formed by the undercut of the wet-etching process[5], over-etching is needed to form the μ-bridge. But the degree of over-etching is difficult to control, because if the over-etching is insufficient, the μ-bridge will not be successfully formed, and the parasitic effects of the device will increase and the RF performance of the device will degrade greatly. However, in contrast, excessive over-etching will increase both the emitter resistance and the base-emitter gap resistance, leading to degradation in RF performance[6]. Moreover, excessive over-etching can destroy the emitter especially when the emitter is very narrow. Second, since there is only one microbridge connected to the emitter, the heat dissipation efficiency degrades.

In this paper, passivation and planarization process techniques using polyimide are developed, and an ultra high-speed InP/InGaAs SHBT with f_t of 210GHz is reported. Compared with the original μ-bridge process, this technique does not need excessive over-etching, so the emitter resistance and the base-emitter gap resistance are smaller and the stability of the process is improved. Also, because this technique uses direct emitter contacting, the heat dissipation will be more efficient on the emitter through the wider metal. Moreover, this technique lays the foundation for the realization of multilevel interconnects in the InP HBT process.

2 Design and fabrication

The epitaxial layer of the HBTs is grown by molecular beam epitaxy on a Fe-doped semi-insulating (100) InP substrate. The layer structure is listed in Table 1. Compared with the epitaxial layer structure in Ref.[4], the total thickness of the emitter-cap layer and the emitter is reduced from 270 to 200nm. Because the wet etching process is used, a thinner emitter will result in smaller undercut that leads to smaller emitter and base resistances[7]. Furthermore, the thickness of the base is reduced from 50 to 40nm because a thinner base results in a shorter base transit time, which leads to higher current gain cutoff frequency. The thickness of the collector is also reduced

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Received 20 September 2007, revised manuscript received 22 October 2007

Table 1 Layer structure for the InP/InGaAs SHBT

Layer	Thickness/nm	Dopant	Doping/cm^{-3}
$In_{0.53}Ga_{0.47}As$	40	Si	3×10^{19}
InP	90	Si	3×10^{19}
InP	10	Si	1×10^{18}
InP	60	Si	3×10^{17}
$In_{0.53}Ga_{0.47}As$	5	Undoped	—
$In_{0.53}Ga_{0.47}As$	40	Be	3×10^{19}
$In_{0.53}Ga_{0.47}As$	40	Si	1×10^{16}
$In_{0.53}Ga_{0.47}As$	5	Si	5×10^{17}
$In_{0.53}Ga_{0.47}As$	200	Si	1×10^{16}
$In_{0.53}Ga_{0.47}As$	30	Si	1×10^{19}
InP	10	Si	1.5×10^{19}
$In_{0.53}Ga_{0.47}As$	50	Si	3×10^{19}
InP	300	Si	3×10^{19}
InP substrate			

from 350 to 275nm, resulting in a higher cutoff frequency. The fabrication process was as follows. First, the device was fabricated using a standard three-mesa process (Fig. 1(a))[4]. Then, two Ti/Au posts were evaporated on both the base metal and the collector metal. The posts move the height of the base metal and the collector metal to the same level as the emitter metal. Next, polyimide was coated, and then etched by oxygen RIE until the emitter metal and two posts were exposed (Fig. 1(b)). Finally, Ti/Au was evaporated to form the bridge and the pad. The SEM picture of the fabricated HBT is shown in Fig. 2.

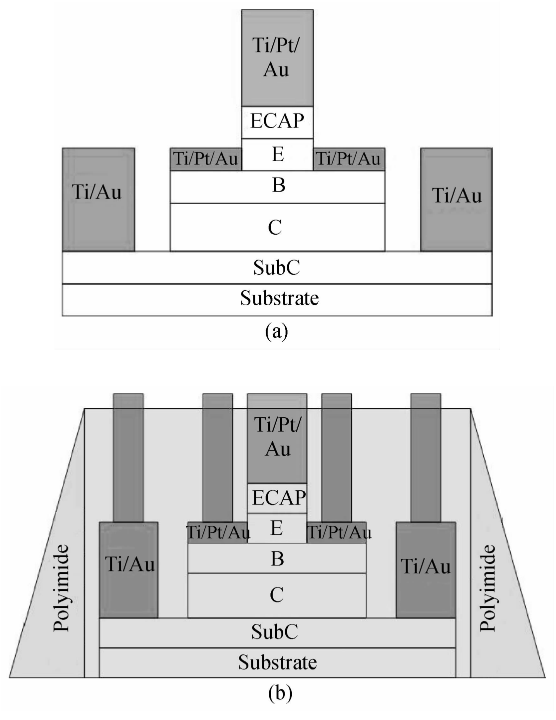

Fig. 1 Process flow (a) After traditional three-mesa process; (b) After planarization with polyimide

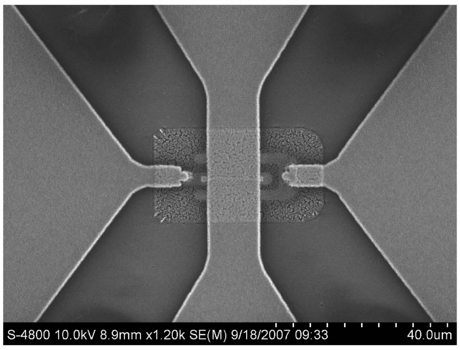

Fig. 2 SEM picture of the fabricated HBT with $1.4\mu m\times15\mu m$ emitter

3 Device measurement results

3.1 DC performance

DC common-emitter characteristics of the HBT with $1.4\mu m\times15\mu m$ emitter are depicted in Fig. 3. The small signal current gain at DC (β) is 91 and the common emitter breakdown voltage (BR_{CEO}) is 3.3V. The measured base sheet resistance is $2184\Omega/\square$, and the specific contact resistivity is $2.4\times10^{-5}\Omega\cdot cm^2$.

3.2 RF performance

The RF performance of the fabricated HBTs was characterized with an HP 8510C network analyzer. Figure 4 shows the current gain (H_{21}) and the Mason's unilateral power gain (U). Extrapolating at −20dB/decade, f_t and f_{max} are 210 and 56GHz, respectively, at $V_{ce}=1.1V$ and $I_c=33.5mA$. We have used Mason's unilateral power gain for extrapolating f_{max} instead of MAG because it is independent of transistor configuration (whether common-base or common-emitter), and it is independent of any pad parasitic[8].

4 Discussion

We have successfully improved the f_t of the de-

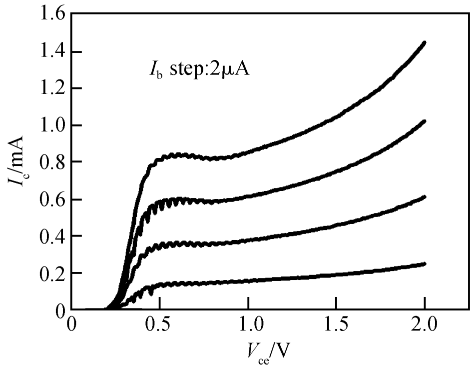

Fig. 3 Common emitter V_{ce}-I_c characteristics of the HBT with $1.4\mu m\times15\mu m$ emitter

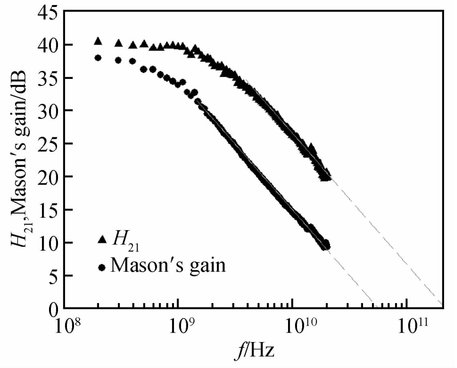

Fig. 4 Frequency dependencies of H_{21} and Mason's gain

vice from 178[4] to 210GHz, but the $f_{\max}$ is disappointing. We now estimate $f_{\max}$ according to Eq. (1)[9]. Here, R_{bb} is the base resistance and C_{cb} is the base-collector capacitance.

$$f_{\max} = \sqrt{f_{\mathrm{t}}/8\pi R_{\mathrm{bb}} C_{\mathrm{cb}}} \tag{1}$$

R_{bb} can be calculated from Eq. (2)[10], where ρ_{s} is the sheet resistance in the base, ρ_{C} is the base specific contact resistivity, L_{e} is the length of the emitter, W_{e} is the emitter width, W_{b} is the base metal width, and W_{eb} is the width of the base-emitter gap caused by undercut. The measured base sheet resistance is 2184Ω/□, and the base specific contact resistivity is $2.4\times10^{-5}\Omega\cdot\mathrm{cm}^2$. With these parameters, we get a 76.5Ω base contact resistance, a 10.9Ω base-emitter gap resistance, and a 16.9Ω base spread resistance, so the total base resistance is 104Ω.

$$\begin{aligned} R_{\mathrm{bb}} &= R_{\mathrm{b,contact}} + R_{\mathrm{gap}} + R_{\mathrm{spread}} \\ &= \frac{\sqrt{\rho_{\mathrm{S}}\rho_{\mathrm{C}}}}{2L_{\mathrm{e}}}\coth\left(W_{\mathrm{b}}\sqrt{\frac{\rho_{\mathrm{S}}}{\rho_{\mathrm{C}}}}\right) + \frac{\rho_{\mathrm{S}} W_{\mathrm{eb}}}{2L_{\mathrm{e}}} + \frac{\rho_{\mathrm{S}} W_{\mathrm{e}}}{12L_{\mathrm{e}}} \end{aligned} \tag{2}$$

C_{cb} is extracted from the S-parameter by plotting the imaginary part of y_{12} versus the frequency (Fig. 5)[10]. From Fig. 5, we find the C_{cb} of the device is about 35fF.

For the fabricated HBT with 1.4μm × 15μm emitter area, f_{t} is 210GHz, R_{bb} is 104Ω, and C_{cb} is 35fF. With these parameters, the estimated $f_{\max}$ according to Eq. (1) is 47.8GHz, which is very close to the extrapolated $f_{\max}$ of 56GHz.

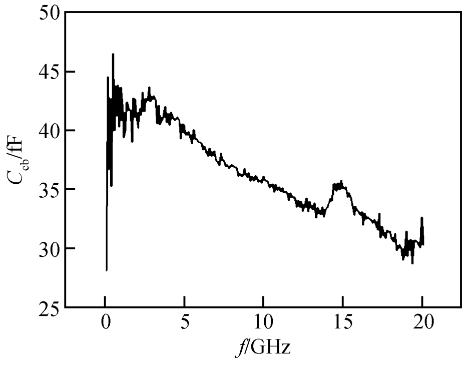

Fig. 5 Frequency dependency of Imag (y_{12})

The base sheet resistance and base specific contact resistivity in Ref. [10] are 600Ω/□ and $2.3\times10^{-7}\ \Omega\cdot\mathrm{cm}^2$, respectively, while our measured parameters are 2184Ω/□ and $2.4\times10^{-5}\ \Omega\cdot\mathrm{cm}^2$. The base sheet resistance and the base specific contact resistivity are too high, leading to very high base resistance. This base resistance is the most important reason why the f_{t} of the device is very high but the $f_{\max}$ remains very low. The current gain (β) at DC of our device is too high compared with Ref. [11], so we can deduce that the doping density of the base does not reach our expectations, which is why the base sheet resistance and the base specific contact resistivity are so high.

5 Conclusion

Ultra high speed InP/InGaAs SHBTs are fabricated with a polyimide passivation and planarization process. By optimizing the epitaxial layer structure, a high frequency performance of f_{t} = 210GHz is obtained with an emitter area of 1.4μm × 15μm. As far as we know, this is the highest f_{t} ever reported for InP-based SHBTs in China.

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f＝210GHz 的超高速 InP/InGaAs 单异质结晶体管

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摘要： 成功地将 Polyimide 钝化平坦化工艺应用于 InP/InGaAs 单异质结晶体管制作工艺中.在 $V_{ce}=1.1V$，$I_c=33.5mA$ 的偏置条件下，发射极尺寸为 1.4μm×15μm 的器件，其 f_t 达到 210GHz.这种器件非常适合高速低功耗方面的应用，例如超高速数模混合电路以及光学通信系统等.

关键词： InP；异质结晶体管；聚酰亚胺；平坦化
EEACC： 2560J
中图分类号： TN385　　**文献标识码：** A　　**文章编号：** 0253-4177(2008)03-0414-04

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2007-09-20 收到，2007-10-22 定稿