InP/InGaAs heterojunction bipolar transistors with different μ-bridge structures*

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Abstract: Several μ-bridge structures for InP-based heterojunction bipolar transistors (HBTs) are reported. The radio frequency measurement results of these InP HBTs are compared with each other. The comparison shows that μ-bridge structures reduce the parasites and double μ-bridge structures have a better effect. Due to the utilization of the double μ-bridges, both the cutoff frequency f_T and also the maximum oscillation frequency f_{max} of the 2×12.5 μm^2 InP/InGaAs HBT reach nearly 160 GHz. The results also show that the μ-bridge has a better effect in increasing the high frequency performance of a narrow emitter InP HBT.

Key words: InP; HBT; μ-bridge

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1. Introduction

InP/InGaAs heterojunction bipolar transistors (HBTs) have many advantages for high-speed and low power applications owing to the excellent properties of the InP and InGaAs material[1]. In order to improve the performance of InP/InGaAs HBT, many technologies have been developed to minimize its parasites[2, 3]. Many of these technologies, such as μ-bridges, were used to reduce the parasitic capacitance. The μ-bridge process has been reported to fabricate high frequency HBTs[4]. For example, an InP/InGaAs HBT using a base μ-bridge structure and an emitter air bridge was reported in Refs. [5, 6]. The cutoff frequency f_T is 178 GHz, and the maximum oscillation frequency f_{max} is 60 GHz. In this paper, HBTs with different μ-bridge structures are reported. A comparison of the radio frequency performance of the HBTs shows the benefits of μ-bridges.

2. Design and fabrication

The selective wet etching of InP and InGaAs shows significant anisotropic effects[7]. At crystal directions parallel to [011], [001] or [010], an undercut is formed under a metal mask such as an emitter metal[8]. In order to form μ-bridges or self-aligning emitters, [011], [001] and [010] are all available directions. However, the etching rate is appropriate to form a small scale self-aligned emitter only at the direction parallel to [011]. According to the characteristics of wet etching of InP and InGaAs, the μ-bridge can be designed in several ways. It can be parallel to [011] or [001]. If the μ-bridge is parallel to the direction of [001], it will form an angle of 45 degrees with the emitter's long side. Then a double μ-bridge structure can be designed with one metal bridge parallel to [001] and the other parallel to [010]. This strategy can also be applied to the emitter design if a μ-bridge is used to connect the emitter electrode.

The epitaxial layers of the fabricated InP HBT were grown on Fe-doped semi-insulating (100) InP substrate by MOCVD. The structure of the epitaxial layer was the same as described in Ref. [6]. The devices were fabricated using a standard mesa process with wet chemical etching and contact photolithography which was described specifically in Ref. [6].

According to the design above, two kinds of μ-bridge structures were fabricated, which are shown in Fig. 1. In Fig. 1(a), the traditional InP HBT reported in Ref. [5] without a μ-bridge is shown for comparison with the new ones.

Table 1 shows the structure parameters of the designed InP HBTs with different base and emitter μ-bridge structures. The denotation of 45° means that the μ-bridge is parallel to the [001] or [010] direction. "Double" or "Single" means that either one or two μ-bridges were designed to connect the electrodes. W_E is the width of the emitter, and W_B is the width of the base on each side of the emitter. The length of the emitters of all the InP HBTs is 12.5 μm.

3. Results and discussion

The common emitter RF performance of the InP/InGaAs HBTs is characterized by an HP8510C network analyzer. The current gain h_{21} and Mason's unilateral gain (U) for the InP HBTs are shown in Figs. 2(a) and 2(b), respectively. The measurement is taken without de-embedding. As shown in Fig. 2, the No.63 HBT reaches the highest f_T and f_{max}, which are 158 GHz and 155 GHz, respectively. Meanwhile the f_T and f_{max} of the No.67 HBT are 146 GHz and 79 GHz, respectively.

The RF performance of the InP HBT is summarized in Table 2. The No.32 and No.33 HBTs which were reported

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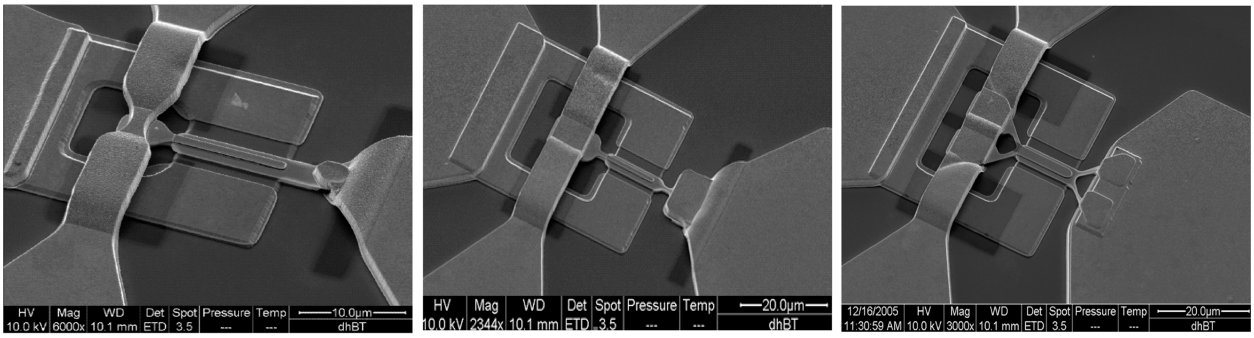
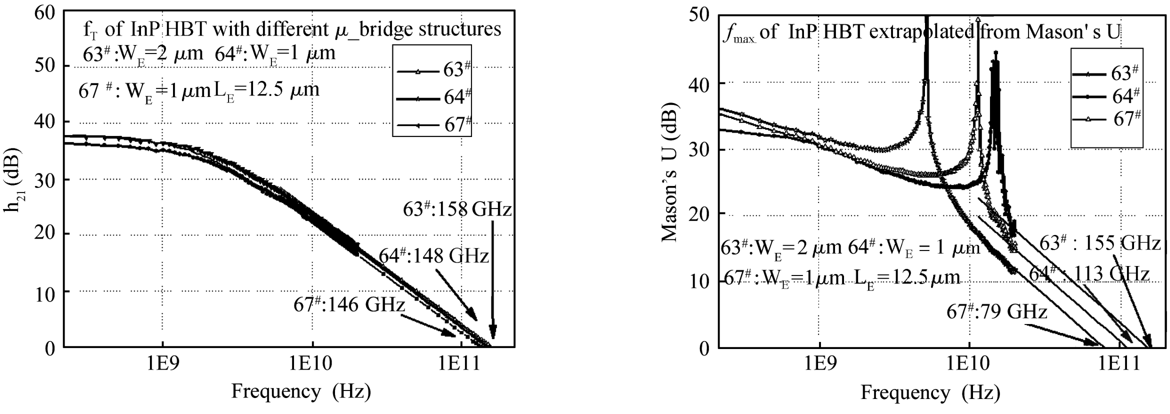


(a) (b) (c)

Fig. 1. SEM pictures of InP HBTs with and without μ-bridges: (a) Traditional InP HBT (No.33); (b) InP HBT with a single μ-bridge for both base and emitter (No.67); (c) InP HBT with double μ-bridges for both base and emitter (No.63).

Table 1. Parameters of different InP HBTs with different base and emitter μ-bridge structures.

HBT No.	Emitter μ-bridge	Base μ-bridge	W_E (μm)	W_B (μm)
63	Double 45° [001] , [010]	Double 45° [001] , [010]	2	1
64	Single [011]	Single [011]	1	1
67	Single [011]	Single [011]	2	1



(a) (b)

Fig. 2. Common emitter RF characteristics of InP HBTs with different μ-bridge structures: (a) Current gain h_{21} and f_T extrapolated; (b) Mason's unilateral gain (U) and f_{max} extrapolated.

in Ref. [5] are traditional HBTs without μ-bridges. According to $f_{max} = \sqrt{f_T/(8\pi \text{Re}(z_b)C_{jc})}$,

$$\text{Re}(z_b)C_{jc} = \frac{f_T}{8\pi f_{min}^2} \tag{1}$$

where $\text{Re}(z_b)$ is the real part of the base input impedance, and C_{jc} is the capacitance of the collector.

The product of the real part of the base impedance and collector capacitance $\text{Re}(z_b)C_{jc}$ is calculated and listed in Table 2. By using a μ-bridge, the product of $\text{Re}(z_b)C_{jc}$ of the No.64 InP HBT is reduced by 53.1% compared to that of the No.32 InP HBT, while that of the No.63 HBT is reduced by 80.3% compared to that of the No.33 HBT. According to Eq. (1), a smaller $\text{Re}(z_b)C_{jc}$ leads to higher f_{max}. For the 2 μm No.63 InP HBT, the f_{max} is improved by 124.6% compared to that of the No.33 InP HBT. The f_{max} of the No.64 HBT and No.32 HBT also has the same trend. This is due to the utilization of μ-bridges. The results show that the μ-bridges clearly reduce parasites.

It is noted that the product of $\text{Re}(z_b)C_{jc}$ of the No.67 HBT is 3.6 times of that of the No.63 HBT. They have the same emitter and base scale but different structures to lead the base and emitter electrodes as shown in Table 1. So the double μ-bridges structure reduces the parasites. Furthermore, the product of $\text{Re}(z_b)C_{jc}$ of the No. 63 HBT is much smaller than that of the No.64 HBT with only a 1 μm wide emitter. For this reason, the f_T and f_{max} of the No.63 HBT are both higher than those of the No.64 HBT. So double μ-bridges have a better effect in reducing parasites than the single μ-bridge.

In Table 2, it can be seen that a smaller emitter width results in higher f_T, f_{max} and the product of $\text{Re}(z_b)C_{jc}$. But the extent of $\text{Re}(z_b)C_{jc}$ reduction is different for InP HBTs with and without μ-bridges when the emitter is narrowed. As the emitter width is narrowed from 2 to 1 μm, the product of

Table 2. RF performance of InP HBTs with different μ-bridge structures.

HBT No.	W_E (μm)	f_T (GHz)	f_{max} (Mason's U) (GHz)	Re(z_b)C_{jc}
32	1	162	81	0.000982
64	1	148	113	0.000461
33	2	159	69	0.001329
63	2	158	155	0.000262
67	2	146	79	0.000931

Re(z_b)C_{jc} of the traditional HBT is decreased by 26.1%, from 0.001329 to 0.000982, while that of the HBT with a single μ-bridge is decreased by 50.4%, from 0.000931 to 0.000461. The latter is much higher than that of the former. This reveals the benefit of the μ-bridge for narrow emitter InP HBTs. The reason for this is as follows: for traditional InP HBTs, $C_{jc,\,Para}$, the parasitic capacitance of the metal lines used to lead electrodes out, the base and emitter pad, is a great part of the total parasitic collector capacitance C_{jc}. To improve the high frequency performance, the width of the emitter is reduced, as is the width of the leading-out metal lines, while the area of the base pad or emitter pad might not be greatly reduced. So $C_{jc,\,Para}$ will not be clearly reduced. Thus, traditional HBTs suffer from the parasites of these parts. But for the InP HBTs with μ-bridges, $C_{jc,\,Para}$ has almost no effect. So for the InP HBT with a μ-bridge, reducing the emitter width will clearly decrease the parasitic capacitance C_{jc} and f_{max} will greatly increase. So the f_{max} of the InP HBT with a μ-bridge will increase greatly as the emitter is narrowed.

4. Conclusions

InP HBTs with different μ-bridge structures were fabricated by the conventional wet chemical etching process. Both f_T and f_{max} of the $2 \times 12.5\ \mu m^2$ InP/InGaAs HBT reach nearly 160 GHz. By utilizing the μ-bridges, the Re(z_b)C_{jc} of the InP HBTs are significantly reduced compared to traditional ones with the same scale. At the same time, the comparison shows that the double μ-bridges structure has a better effect in reducing parasites than the single one, and the μ-bridge has a better effect in increasing the high frequency performance of narrow emitter InP HBTs.

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