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Super Performance InGaP/GaAs HBT with Novel Structure*

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Abstract: A kind of super performance InGaP/GaAs HBT with f_T = 108GHz and f_{max} = 140GHz is demonstrated. The excellent frequency performance results from the novel structure of the U-shaped emitter, together with self-aligned emitter and LEU (lateral etched undercut) technologies. The HBT with the novel structure shows a distinguished performance with BV_{CEO} up to 25V. And excellent performance of low V_{offset} of 105mV and V_{knee} of 0.50V is great favor of low power applications. The differences due to the different structure are also compared.

Key words: heterojunction bipolar transistor; U-shaped emitter; self-aligned emitter; thermal handling capacity
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1 Introduction

With the rapid development of mobile communication, heterojunction bipolar transistor (HBT) becomes one of the most important devices in the microwave and millimeter wave field due to its distinguished performance and high reliability. Compared with HEMT, the distinguished characteristics of high power density, high transconductance, together with a relatively low requirement of lithography precision make HBT especially applicable for laser driver, RF power amplifier, and etc. And the popular InGaP/GaAs HBT becomes the first choice in RF circuit design because of the strongpoint of higher efficiency, higher reliability, and higher yield[1~3].

As known to all, C_{bc} is a bottleneck to the frequency performance of HBT. In this paper, we adopted a novel U-shaped emitter, together with self-aligned emitter and LEU (lateral etched undercut) technologies to minimize the C_{bc} and to improve the frequency performance remarkably. The novel HBT with the emitter areas of 1.5μm × 10μm × 2 + 4μm × 3.8μm in this work, has reached f_T above 100GHz, and f_{max} up to 140GHz. More important is that the HBT with the U-shaped emitter has an advantage in the thermal effect over the traditional HBT with the emitter area of 3μm × 15μm.

2 Experiment and fabrication

2.1 Epitaxy layer design

The epitaxy structure plays a key role in the device performance. A 100mm InGaP/GaAs epitaxial wafer by MOCVD is used in this work and the structure of the epitaxy layers is shown in Fig. 1. In this structure, the cap layer with the graded component loosens the stress between the cap layer

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and emitter layer. What is more, high concentration of indium in the cap layer can realize a good ohmic contact between the emitter metal Ti/Pt/Au and the cap layer. High concentration of carbon about $4\times10^{19}cm^{-3}$ in the base is beneficial to low base resistance and high frequency performance.

Layer	Material	Doping		Thickness
Emitter-cap	$In_xGa_{1-x}As$ (x=0.5) ↓ GaAs	$>1\times10^{19}cm^{-3}$	n^{++}	100nm
	GaAs	$5\times10^{18}cm^{-3}$	n^{++}	120nm
Emitter	$In_xGa_{1-x}P$ (x=0.51)	$3\times10^{17}cm^{-3}$	n	50nm
Base	GaAs	$4\times10^{19}cm^{-3}$	p^{++}	60nm
Collector	GaAs	$3\times10^{16}cm^{-3}$	n^{-}	700nm
Sub-collector	GaAs	$5\times10^{18}cm^{-3}$	n^{++}	500nm
Si substrate				

Fig. 1 Epitaxy layer structure

2.2 Device process

Generally speaking, C_{bc} is the main nonlinear factor in HBT and has a strong negative effect on the linearity and the frequency performance, especially on f_{max}. So special methods are needed to minimize C_{bc}, especially when we fabricate the transistor with very high frequency[1].

In this work, we adopt several novel process methods such as the self-aligned emitter, LEU, etc[2,3]. As far as the self-aligned emitter, the emitter metal works as the mask to form emitter, and further realizes the self-aligned base metal. In this way, we can reduce the base serial resistance and the collector capacitance. LEU technology, with use of selective etchant, removes majority of extrinsic base-collector junction areas. Thus the gap between the base layer underneath the base contacts and the subcollector is filled with the air with the lowest relative dielectric constant. As shown in Figs. 2 and 3, we can see that C_{bc} is reduced greatly. As a matter of fact, the measurement data from IC-CAP also show that the C_{bc} is much smaller in the HBT with the U-shaped emitter (Fig. 4) than that of the traditional HBT (Fig. 5). On the other hand, as HBT is a kind of vertical device, in order to improve the yield, we adopt emitter airbridge and two layers of metallization, which effectively prevented the wire break at the edges.

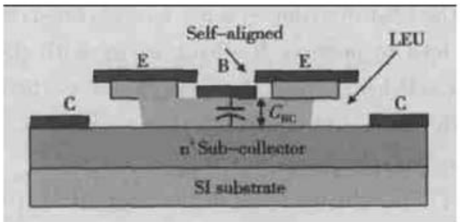

Fig. 2 Cross-section of the novel HBT

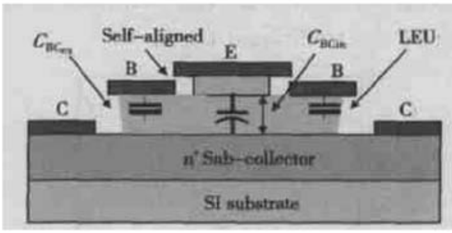

Fig. 3 Cross-section of the traditional HBT

3 Device design

As known to all, there is a self-heat effect in HBT, that is, with the rise of the current density, the device temperature arises quickly under the influence of the self-heat and power dissipation from nearby devices. What is the worst is that the positive feedback between the current and the temperature makes the device worsen, or even collapse, that is so called gain collapse. Thus HBT can only work smoothly below a certain current density; otherwise the characteristics will worsen and affect the practical applications[1].

In practical applications, people adopt several ways to avoid the gain collapse, one of which is adding ballasting resistance, with the aim at balancing the current and meliorating the thermal distribution. When we use base ballasting resistance, a parallel capacitance is needed to form a RF path. But in this way, ballasting effect only exists in DC condition. And the emitter ballasting resistance often suffers from the process tolerance variation.

Thus the higher thermal handling capacity of the device itself is the key to improve the circuit performance.

As to the traditional HBT with the single emitter (Fig. 6), when the current density is very high, the heat distributes more concentrated, which could lead to positive feedback easily with the result of self-heat effect. However, as far as the HBT with the U-shaped emitter in this design (Fig. 7), it has the advantages as follows:

(1) The emitter areas of the novel HBT are the same as those of the traditional HBT, which means that the current the novel HBT can hold is no less than that of the traditional HBT.

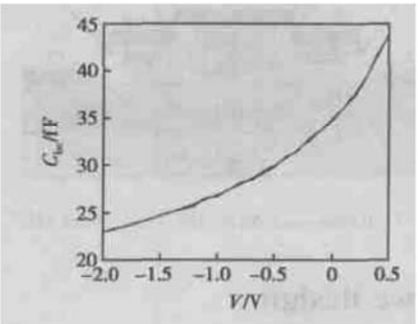

Fig. 4 Measured result of C_{bc} of the novel HBT from IC-CAP

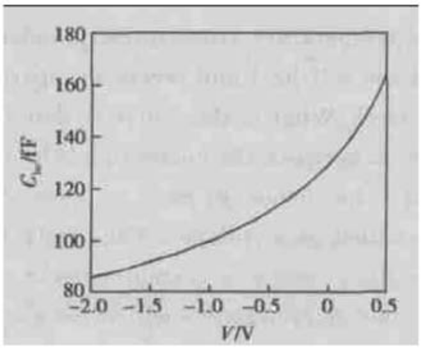

Fig. 5 Measured result of C_{bc} of the traditional HBT from IC-CAP

(2) 1.5μm, the minimum emitter width in the novel HBT, is far less than 3μm of the emitter in width of the traditional HBT. And self-aligned emitter and LEU technologies adopted greatly reduce the C_{bc}, thus the frequency performance of the novel HBT is much higher.

(3) Under the same current condition, the current distributes at two fingers of the novel HBT, which means that the distribution is more even than that in the traditional HBT. Thus it results in a lower junction temperature and a better thermal handling capacity, which make it more applicable for the power applications[4].

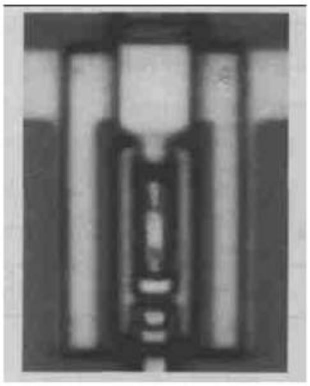

Fig. 6 HBT with the traditional emitter

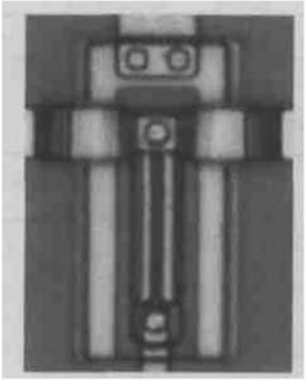

Fig. 7 High performance HBT with the U-shaped emitter

(4) The base-collector junction in the traditional HBT is as much as 6μm in width, while that in the novel HBT is only 3μm, which further reduces C_{bc} with the result of higher frequency performance.

4 Results and discussion

Measurement data of the novel HBT show advantages over the traditional HBT.

(1) Better DC performance

Large V_{offset} and V_{knee} are obstacles to low power applications and low V_{offset} and V_{knee} are highly appreciated.

From the data measured by HP 4155A parameter analyzer, we can see that the HBT with the U-shaped emitter has an excellent DC performance (Fig. 8). As shown in Fig. 9, the HBT with the U-shaped emitter has 105mV of V_{offset}, while the V_{offset} of the traditional HBT reaches 130mV. On the other hand, the V_{knee} of the novel HBT (collector current density of $3.3 \times 10^4 A/cm^2$) is only 0.50V, while the V_{knee} of the traditional HBT shown in Fig. 9 reaches as much as 0.65V. Thus the HBT with the U-shaped emitter shows an advantage over the traditional HBT in low power applications.

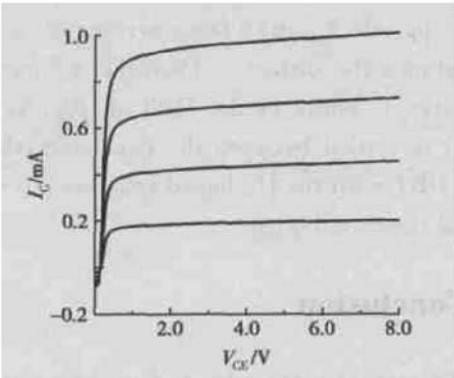

Fig. 8 I_C-V_{CE} curves of the novel HBT

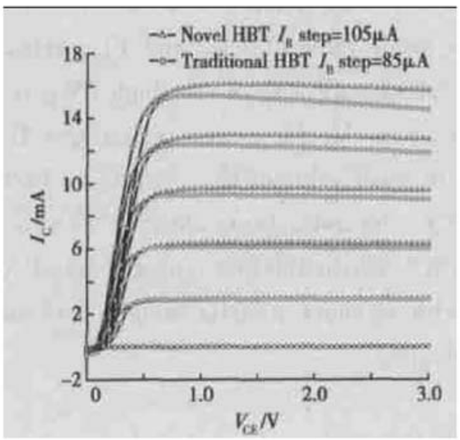

Fig. 9 Detailed I_C-V_{CE} curves of HBTs with I_C up to 15mA

(2) Higher breakdown performance

With the virtue of the lower junction temperature, the novel HBT also shows a better breakdown performance. In this experiment, we compared the differences between the BV_{CEO} of the two kinds of HBT cell with three fingers (Fig. 10). As shown in Fig. 11, on the condition of collector current compliance of 100μA, BV_{CEO} of the HBT with the U-shaped emitter can reach as much as 25V, while on the same condition, the BV_{CEO} of the traditional HBT can only reach about 13.5V. Obviously, the HBT with the U-shaped emitter is more applicable for the high power applications.

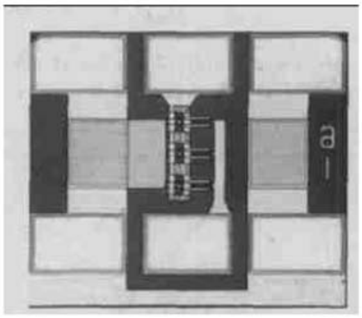

Fig. 10 HBT cell with three fingers used in model extraction

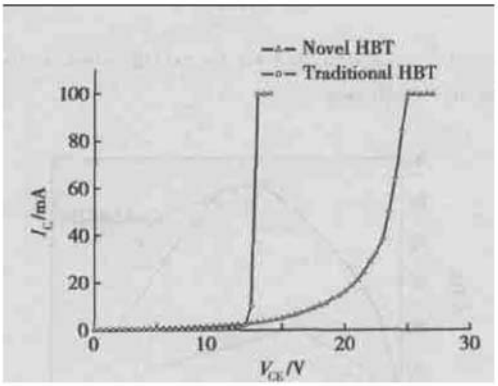

Fig. 11 Illustration of BV_{CEO} of HBTs

(3) Higher frequency performance

Due to the U-shaped emitter, together with special methods, such as self-aligned emitter, LEU technologies, used in the device fabrication, the C_{bc} is greatly reduced. Thus high frequency performance is greatly improved. Measurement based on IC-CAP showed that the f_T of the HBT with the U-shaped emitter can reach above 100GHz (Fig. 12), and the f_{max} can reach as much as 140GHz (Fig. 13), while the traditional HBT in the same wafer can only reach 83.6GHz of f_T (Fig. 14). It is shown that HBT with the U-shaped emitter is an attractive choice for the ultra high-speed circuits.

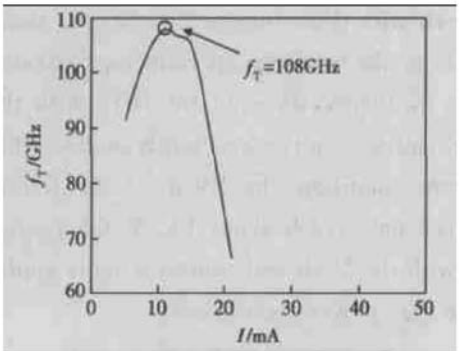

Fig. 12 Measured result of the novel HBT's f_T above 100GHz from IC-CAP

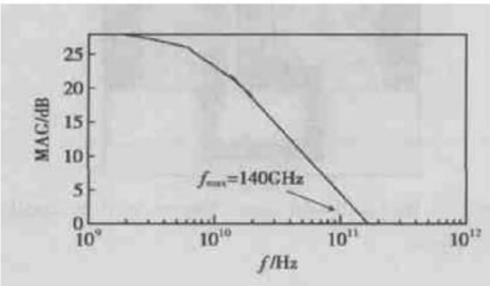

Fig. 13 f_{max} up to 140GHz by extrapolation at the rate of - 20dB/dec

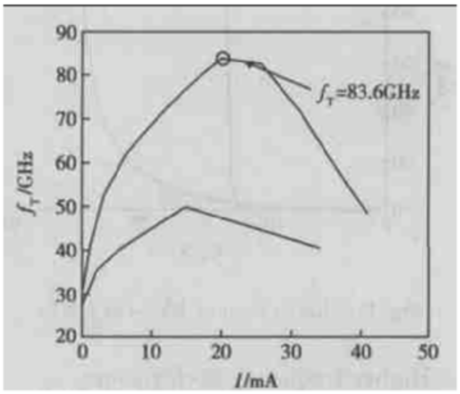

Fig. 14 Measured result of the traditional HBT's f_T of 83.6GHz from IC-CAP

On the other hand, through the comparison of data in Fig. 10, we can find that the HBT with the U-shaped emitter shows a smaller h_{fe} compared to the HBT with the traditional structure. From Fig. 15, we could find that the base current ideal factor is 1.66. That is, the trapped recommendation current in the base-emitter space-charge region dominates the base current. As shown in Fig. 2, the current passes directly from the emitter to the collec-

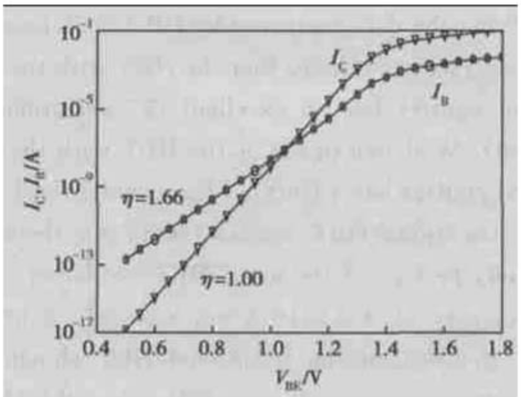

Fig. 15 Gummel plot of the HBT with the U-shaped emitter

tor, during which quite a large percent of current is trapped near the surface and becomes recommendation current. While in the HBT in Fig. 3, as the emitter is settled between the two bases, the case in the HBT with the U-shaped emitter does not occur and the h_{fe} is higher.

5 Conclusion

We demonstrated a kind of super performance InGaP/GaAs HBT with the novel U-shaped emitter. The DC characteristics of the novel HBT show quite a small value of V_{offset} and V_{knee}, separately 105mV and 0.50V. 25V, a very high BV_{CEO}, makes it more applicable for power applications. Due to the quite small value of C_{bc}, 108GHz, an excellent f_T, and f_{max} for 140GHz are obtained with the help of IC-CAP. This is the first report of InGaP/GaAs HBT with f_T above 100GHz using 1.5μm process technologies.

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高性能新结构InGaP/GaAs异质结双极型晶体管*

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摘要: 报道了一种采用U形发射极新结构的高性能InGaP/GaAs HBT. 采用自对准发射极、LEU等先进工艺技术实现了特征频率达到108GHz, 最大振荡频率达到140GHz的频率特性. 这种新结构的HBT的击穿电压达到25V, 有利于在大功率领域应用. 而残余电压只有105mV, 拐点电压只有0.50V, 使其更适用于低功耗应用. 同时, 还对比了由于不同结构产生的器件性能的差异.

关键词: 异质结双极型晶体管; U形发射极; 自对准发射极; 热处理能力

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