Development of Microwave SiGe Heterojunction Bipolar Transistors*

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Abstract: The microwave SiGe Heterojunction Bipolar Transistors (HBT) were fabricated by the material grown with home-made high vacuum/rapid thermal processing chemical vapor deposition equipment. The HBTs show good performance and industrial use value. The current gain is beyond 100; the breakdown voltage BV_{ceo} is 3.3V, and the cut-off frequency is 12.5GHz which is measured in packaged form.

Key words: SiGe; HBT

EEACC: 2560J; 2520M

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1 Introduction

SiGe material of great practical value can introduce the band-engineering conception into the Si process. It provides another important device with design option and can greatly improve the device performance. Now the best result reported is cut-off frequency (f_T) of 130GHz[1] and maximum oscillation frequency (f_{max}) of 160GHz[2]. A relatively practical process introduced by IBM and TEMIC shows f_T and f_{max} to be 30—50GHz[3].

The international research results have been applied to volume production, while the domestic research is still in the laboratory stage with some simulation results published[4]. Our home-made High Vacuum/Rapid Thermal Processing Chemical Vapor Deposition (HV/RTCVD) equipment[5] is capable of producing strained SiGe films with device quality at low temperature on 4-inch wafers. In addition, the devices, including diodes and HBT's fabricated by such material show good performance. So the capability and practicability of the equipment and their fabrication process are proved.

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This paper has four parts including the Introduction. In section Ⅱ, the HBT's structure and growth procedure are introduced briefly. Section Ⅲ describes the fabrication process of HBT. Then the device DC and the high frequency characteristics are presented. The conclusion is drawn in the last part.

2 Device Structure

Our purpose is to fabricate low noise HBTs, which can work under 5V with frequency ranging from 1 to 2 GHz, to be used for the wireless communication applications mainly. So we put our emphasize on the overall performance, the process and some tradeoffs, instead of some target only. And thus, the very thin base layer was not chosen. The base layer thickness is chosen as 60nm and the targeted f_T 15GHz[6]. It shoud be indicated that the power performance, e. g. f_{max}, can be satisfied very well at the same time. The device design will be reported in another article. The current gain increase with the increase of germanium fraction in the base layer. However, very high germanium fraction is unfavorable for the layers's stability. According to our requirement, the fraction was chosen to be 0. 2. The collector's thickness and the dopant concentration decide the breakdown voltage. The dopant concentration was chosen as $1\times10^{17}cm^{-3}$ in order to improve the performance under high current density. The layer thickness was determined to be 500nm considering the dopant diffusion and the base push out effect. Therefore, the working voltage is 5V. The whole structure is shown in Figure 1.

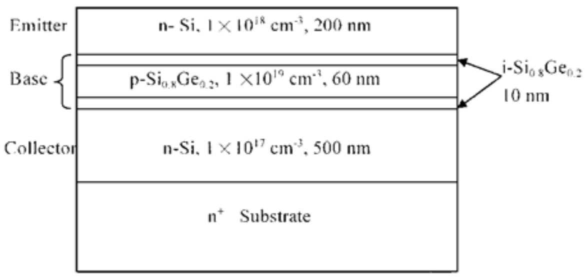

FIG. 1 Vertical Structure of HBT

The double mesa process was adopted, with the area of emitter equal to that of mesa. Now the emitter strip width is 2μm. The implantation of base contact is self-aligned to the emitter mesa, as is beneficial to the reduction of the base series resistance and the overall R_b as well. The length of emitter strip is decided to be 10μm as a trade-off between R_b and C_{je}.

3 Process

The procedure of double-mesa HBT structures fabrication is listed below:

1) Implantation of As (energy of 30 keV and dose of $1\times10^{15}/cm^2$) for the emitter contact;

2) Low temperature growth of SiO_2;

3) Dry etching of emitter mesa;

4) Low temperature growth of SiO_2; dry etching to form the sidewalls;

5) Implantation of BF_2 (energy of 25 keV, dose of $1\times10^{15}/cm^2$) and B (energy of 30 keV, dose of $1\times10^{15}/cm^2$) for the base contact;

6) Dry etching the collector mesa;

7) Lower temperature growth of SiO_2; etching the SiO_2 inside the mesa with other area masked by the photo resist;

8) Lower temperature growth of SiO_2;

9) Rapid thermal annealing (15 second at the temperature of 850 ℃);

10) Opening the contact holes of emitter and base;

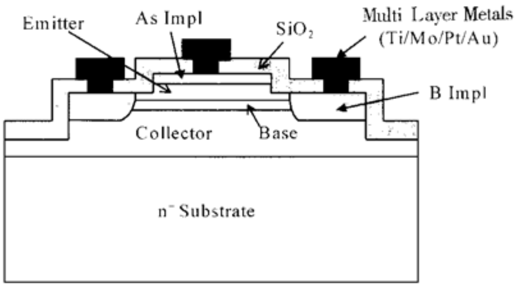

FIG. 2 Final HBT Device Structure

11) Sputtering Pt; forming PtSi alloy in the contacting area by annealing in 600℃; removing the un-reacted metals by aqua regia;

12) Sputtering the multi film of Ti/Mo/Pt/Au, electroplating Au film after the photolithography of EB metal strips, then back etching Au/Pt/Mo/Ti;

13) Thinning the substrate to 120 μm, evaporating Au on the backside and scribing die;

14) Sintering, welding the Au filament;

15) Encapsulated by the metal-ceramic-microstrip package.

Figure 2 is the final device structure.

4 Results

The DC characteristics are measured by the HP4145A semiconductor parameter analyzer. Figure 3 is the output characteristics, with the current gain to be 100. The CB and EB junction's breakdown feature is hard and the leakage current is about 2 nA/μm^2. The breakdown voltage of EB junction is 5.6 V, and that of junction is 11.2 V. The open collector's breakdown voltage BV_{ceo} is about 3.3V.

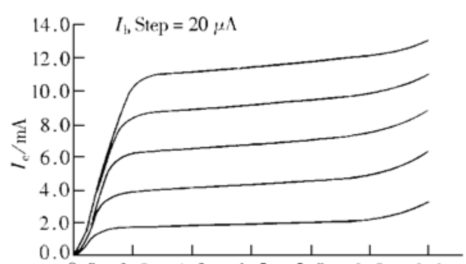

FIG. 3 Typical Output Characteristics

The current gain of 100 can be deduced.

As for the microwave performance, the network parameter (S parameter) has been tested. The instrument is HP8510A. Converting the S parameter into the h parameter, we can deduce the cut-off frequency f_T. f_T is the frequency when the magnitude of h_{21} is equal to 1. The device has an emitter area of $2\times2\times10\mu m^2$. At a working point where $V_{ce}=$ 2V and $I_c=$ 20mA, the maximum f_T of 12.5GHz can be extracted.

Because no de-embedding procedures are adopted here, and the package will definitely introduce parasitic inductance and capacitance that can degrade the frequency characteristics, the device intrinsic f_T will be higher than the measured value. After a simple de-embedding procedure, we can estimate f_T to be 15GHz for sure. Figure 4 is the relationship of f_T and I_c. The maximum current density if 0.5mA/μm² when f_T reaches the maximum value, which is near the theoretic value of 1mA/μm² considering the current crowding effect and the measuring error. The calculation[6] proves the noise figure is less than 1.4dB at 1GHz. The measured value will be given later.

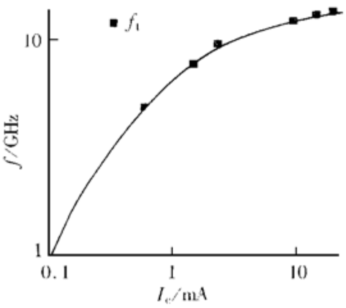

FIG. 4　Relation Between Cut-Off Frequency and Collector Current $A_E = 40\mu m^2$

5 Conclusion

The home-made epitaxy system is capable of strained SiGe material growth. The SiGe HBT fabricated by this material shows good performance. The device current gain is beyond 100, BV_{ceo} = 3.3 V, breakdown voltage of CB and EB junction is 11.2V and 5.6V respectively. This is applicable to the low voltage wireless communications. The leakage current is 2 nA/μm², which is another proof of the material's device quality. The cut-off frequency f_T after packaging is 12.5 GHz.

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