World Journal of Engineering and Technology, 2015, 3, 1-5
Published Online November 2015 in SciRes. http://www.scirp.org/journal/wjet
http://dx.doi.org/10.4236/wjet.2015.34B001

A Ge-Graded SiGe HBT with $\beta > 100$ and $f_T = 67$ GHz

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Received 12 August 2015; accepted 13 November 2015; published 20 November 2015

Abstract

By using reduced pressure chemical vapor deposition (RPCVD), the high strained, Ge-graded SiGe film growth has been realized. The film was used as a base of the HBT (Heterojunction Bipolar Transistor) developed in 0.35 μm SiGe BiCMOS process technology, and made the device give good DC characteristics ($\beta > 100$) and high-frequency performance ($f_T = 67$ GHz), thus meeting the requirements for technical specifications in 0.35 μm SiGe BiCMOS process technology.

Keywords

RPCVD, SiGe, HBT, Graded Profile, SiGe BiCMOS

1. Introduction

With its unique band structure and strain characteristic, SiGe materials have been widely used to improve the performances of MOSFET (metallic oxide semiconductor field effect transistor) and HBT device. Due to change in band structure, SiGe HBT, produced by incorporating Ge (Germanium) into base of bipolar transistor, obtains better device performances such as low noise, high frequency, high speed [1]. The theoretical research suggests that Ge composition profile in SiGe base of HBT influences both DC characteristic (e.g. gain β) and AC characteristics [2]. If Ge composition profile is graded (*i.e.* Ge composition changes gradually from high Ge content in collector region to low Ge content in emitter region), then an accelerating electric field in HBT base region will be developed, which shortens the time electron transits base region, thus enhancing further frequency of SiGe HBT. The gain of device in Ge-graded base, however, will decrease to a certain extent. Therefore, a properly graded profile is good for improving frequency of device, and in the meantime, ensures that the gain of the device meets the requirements for specifications of circuits.

In this study, the high-quality SiGe film growth implementing Ge-graded profile (15.5% - 0%) has been developed using ASM E2000plus reduced pressure chemical vapor deposition (RPCVD) equipment [3] [4]. Material quality and structural parameter were characterized by XRD (X-ray diffractometer) and SIMS (Secondary ion mass spectroscopy), respectively. As this base epitaxial growth meets specifications of the 0.35 μm SiGe BiCMOS process technology, it is used as a key process of 0.35 μm SiGe BiCMOS technology. By using the base epitaxial growth, the high-performance SiGe HBT with $\beta > 100$ and $f_T = 67$ GHz has been developed suc-

How to cite this paper: Zhang, J., Yang, Y.H., Chen, G.B., Wang, Y.X., Hu, D.B., Tan, K.Z., Cui, W. and Tang, Z.H. (2015) A Ge-Graded SiGe HBT with $\beta > 100$ and $f_T = 67$ GHz. *World Journal of Engineering and Technology*, **3**, 1-5.
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cessfully.

2. Experiment and Results

2.1. SiGe Base Epitaxial Growth with Ge-Graded Profile

HBT base SiGe film deposition uses ASM E2000plus reduced pressure chemical vapor deposition (RPCVD) equipment. Unlike substrate cleaning of conventional epitaxy, the wafers were dipped into dilute HF solution after being cleaned by standard RCA cleaning in order for H atoms to passivate wafer surface completely, then were dehydrated, and finally were put into RPCVD machine. This treatment is aimed at eliminating the need of high-temperature treatment to prevent MOS structure, formed through preceding steps, from changing. Only 2-minutes baking at 900˚C would obtain a clean, oxygen free, epitaxial growth surface. To further reduce thermal budget, SiH_2Cl_2 was replaced by SiH_4 as Si source. GeH_4 is used as Ge source, dopant source uses B_2H_6, and deposition temperature was 650˚C. SiGe stack layers for Ge-graded profile were composed of 5 steps. At a constant SiH_4 flow of 20 sccm, Ge-content graded downward by gradually reducing GeH_4 flow from 60 sccm to 0.

Figure 1 is the designed, RPCVD-deposited HBT multi-layer structure. Layer 1 is 15 nm thick, 15% Ge, uniform profile, undoped SiGe. Layer 2 is 22 nm thick SiGe with Ge-graded profile (15% to 0%) at B dopant concentration of 2e19 cm^{-3}. Layer 3 is 40nm thick Si cap at B dopant concentration of 5e18 cm^{-3}. **Figure 2** is SIMS-measured thicknesses, Ge and B profiles, tallying with what were designed. **Figure 3** is SiGe base rocking curve measured by high-resolution X-ray diffractometer (XRD). **Figure 4** is reciprocal space map measured by XRD. From **Figure 3** and **Figure 4**, it can be concluded that the quality of SiGe stack layers was good, that SiGe stack layers were fully strained, and that there was no relaxation in SiGe stack layers.

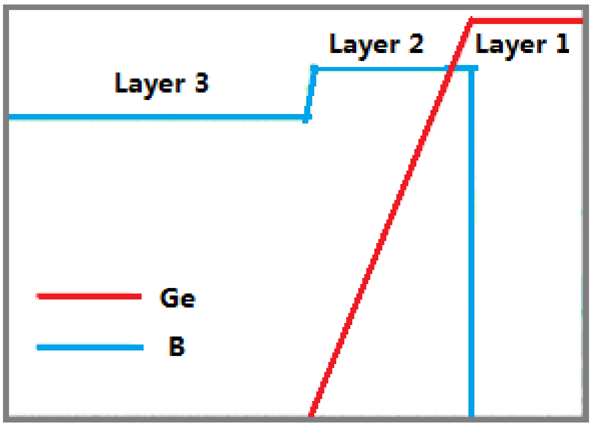

Figure 1. Designed parameters of RPCVD growth structure.

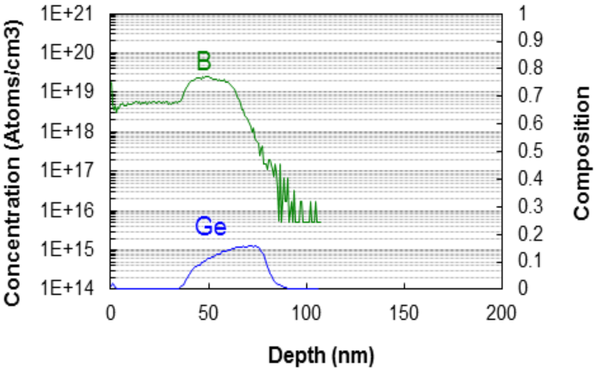

Figure 2. SIMS-measured Ge and B profiles.

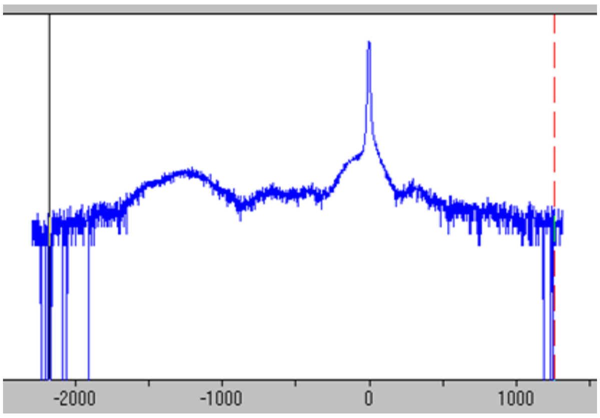

Figure 3. SiGe base rocking curve by XRD.

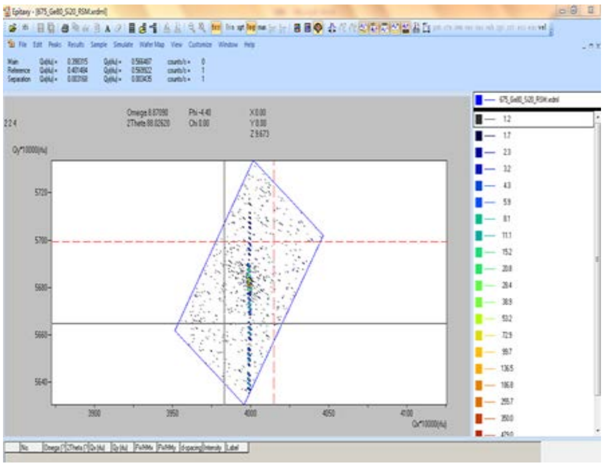

Figure 4. Reciprocal space map measured by XRD.

2.2. Key Technologies of HBT Device

As strain exists in SiGe, SiGe is restricted by temperature throughout SiGe processing. To reduce affection of thermal technology, HBT production in 0.35 μm SiGe BiCMOS process technology was after MOS formation, avoiding thermal processes such as source/drain implantation annealing, gate oxidation. HBT device used mainly deep trench isolation technology in order to reduce the parasitic effect and favor f_T improvement; outer base region used metal silicide ($TiSi_2$) in order to reduce R_b and make for decreasing noise figure; selectively injected collector (SIC) process was used to decrease R_e, thus suppressing bulk injection effect and enhancing β and f_T; dual poly (outer base rejoin, emitter rejion) process was used to reduce C_{jc} and C_{je}, to reduce RC delay, and also to favor increasing f_T.

2.3. Device Performances

HBT device performance parameters, including the DC and AC parameters, were tested. **Figure 5** is HBT I-V output characteristic curve, **Figure 6** is HBT Gummel curve, **Figure 7** is HBT Beta curve, and **Figure 8** is HBT frequency characteristics ($f_T = 67$ GHz). Current gain of HBT device is 150, and cutoff frequency of HBT device is 67 GHz.

3. Conclusion

In this study, with reduced pressure chemical vapor deposition (RPCVD), the high strained, Ge-graded SiGe film growth has been achieved. The film was used as a base of the HBT (Heterojunction Bipolar Transistor) developed in 0.35 μm SiGe BiCMOS process technology, and made the device give good DC characteristics ($\beta >$

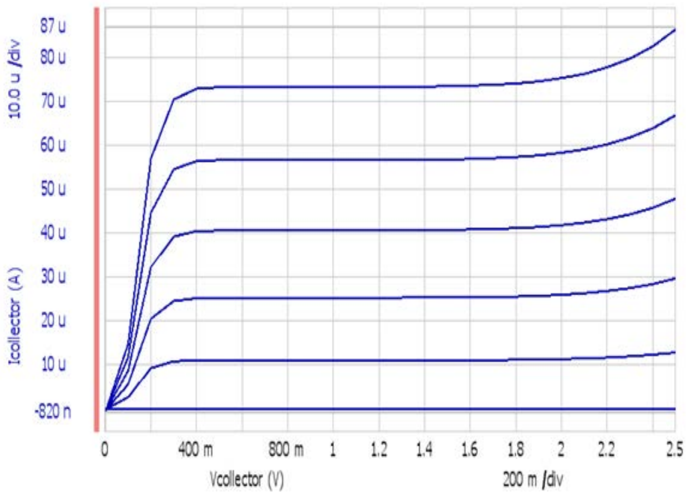

Figure 5. HBT I-V output characteristic curve.

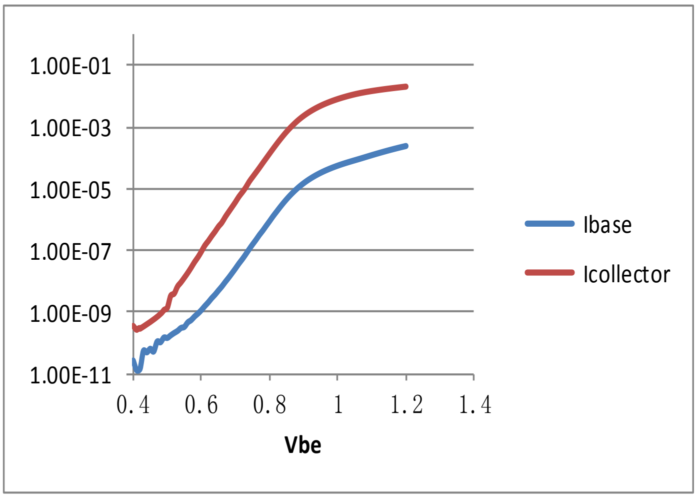

Figure 6. HBT Gummel curve.

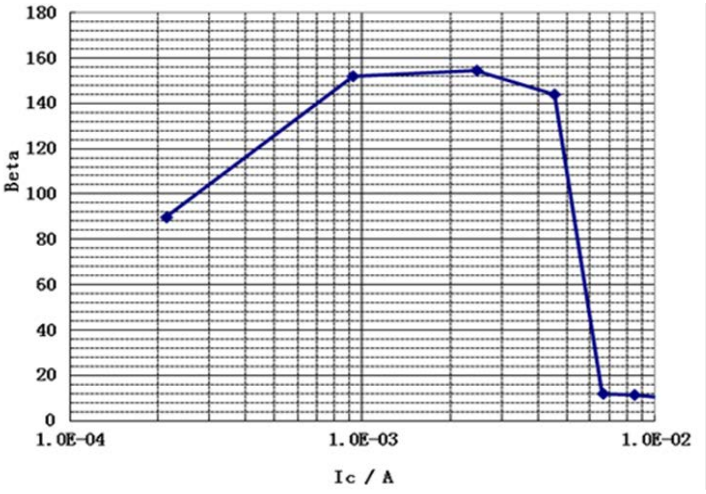

Figure 7. HBT Beta curve.

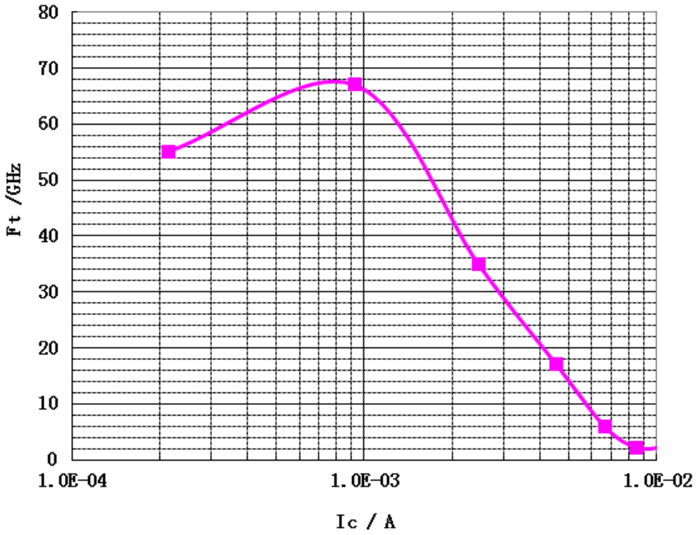

Figure 8. HBT frequency characteristics (f_T = 67 GHz).

100) and high-frequency performance (f_T = 67 GHz), thus meeting fully the requirements for technical specifications in 0.35 μm SiGe BiCMOS process technology.

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