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Epitaxy of SiGe HBT Structure by High Vacuum/Rapid Thermal Processing/Chemical Vapor Deposition*

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Abstract: The strained SiGe material has been grown by using the newly developed High Vacuum/Rapid Thermal Processing/Chemical Vapor Deposition (HV/RTP/CVD) system. Device-quality material is grown by handling process after careful design. The Ge fraction varies up to 0.25, and the n and p type doping is well controlled, which are both adapted to the fabrication of Heterojunction Bipolar Transistors (HBT). The SiGe HBT structure, namely n-Si/i-p$^+$-i SiGe/n-Si structure, has been investigated, with which, the HBTs are fabricated and show good performance. The new system has been proved potential and practicable.

Key words: CVD; SiGe; HBT
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1 Introduction

Epitaxial strained SiGe material can be fabricated in several ways, including Ultrahigh Vacuum/Chemical Vapor Deposition (UHV/CVD)[1], Molecule Beam Epitaxy (MBE)[2,3] and Rapid Thermal Chemical Vapor Deposition (RTCVD)[4]. Using these methods, we can achieve good materials and devices. However, these systems are complex, high cost and hard to operate or maintain. So HV/RTP/CVD system with simple structure has been developed on the basis of rapid thermal processing and other UHV/CVD systems. It is designed to easily operate and also to produce the material with device quality. In addition, the process of Si/SiGe low temperature epitaxy has been investigated systematically[5].

SiGe HBT is promising in the field of wireless microwave communication. Therefore, the n-Si/i-p$^+$-i SiGe/n-Si structure that is qualified to the fabrication of mesa-typed HBT has been investigated. The HBT device demonstrates the good performance, which proves the material's quality and the equipment's capability.

2 Equipment

As shown in Fig. 1, the equipment mainly consists of two parts, wafer loading chamber and growth chamber. The two ports are isolated by the atmosphere when loading/unloading the wafers, so the growth chamber can be kept in a high vacuum. The growth chamber is a quartz chamber, long and flat. Quartz has low pollution to the Si wafer, while its tabular shape is designed for the uniform high efficiency heating. The heater is made of high-purity graphite that encloses in a quartz

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chamber at where the Si wafer lies. Heated by direct current, the temperature of the graphite changes at a high rate. The wafer is heated by the graphite's infrared radiation. In the range of SiGe growth temperature about 850—900K, the radiation energy can be transferred through the quartz chamber almost lossless. In addition, because the graphite heaters are close to the Si wafer, the thermal efficiency is rather high. In order to reduce the oil pollution, the vacuum system is often pumped down by molecule pumps. Due to the small volume of the growth chamber, the base vacuum can be achieved fast. Controlled by a computer, the system is easy as to complete the whole operation procedure. Some specifications are listed below: base vacuum: 2×10^{-6} Pa; working pressure: 0.1—0.2Pa; growth temperature: 500—900℃.

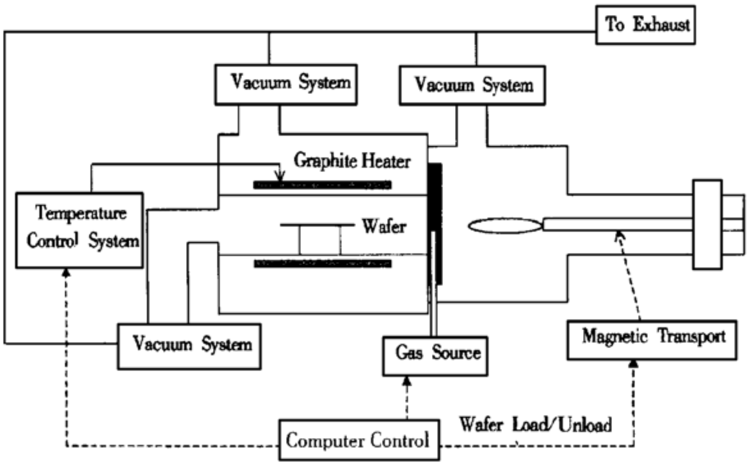

FIG.1 Schematic of HV/RTCVD System

3 Growth Methodology

The method of growing the strained SiGe material has been developed according to the system's features. The system is designed based on the UHV/CVD system proposed by Meyerson[1], i.e., the system vacuum should be improved when we lower the growth temperature, in this way, good epitaxy films can be obtained. When the growth temperature is 550℃, the fractional pressure of water is below 2.5×10^{-9}Pa. Theoretically, contrary to the conventional high-temperature epitaxy, the hydrogen passivation is so effective that no surface pre-clean is necessary during the fabrication of the good epitaxy material.

However, since our system cannot reach that high vacuum level, both the hydrogen passivation and pre-clean are performed. It is important to keep the Si substrate from pollution. Therefore, the Si wafer should be kept in a low vacuum environment for a shorter time. In a boiled solution of $H_2SO_4:H_2O_2=4:1$, the wafer was chemically cleaned for 15min, and then rinsed in de-ionized water for at least 10min. Before being put into the loading chamber, it should be dipped in diluted HF solutions for 30s. The loading room had been pumped down rapidly. When the vacuum reached 10^{-5} Pa after 5min or so, the wafer was put into the growth chamber. The vacuum approaching to the base vacuum, the temperature would be rised to 750—800℃ at a high rate. Heating in the vacuum for 5min, the temperature would descend to the growth temperature, for Si, 600℃; for SiGe, 550℃. Then the growth process began. Because the temperature could be increase and/or decrease very fast, the probability of being polluted is very low, so the initial clean surface required could be obtained. The gas source is SiH_4, GeH_4, B_2H_6 and PH_3, all of which are of the purity of ppm level. Only in a clean growing ambience, the epitaxy can proceed. Figure 2 is the Rutherfold Back Scattering (RBS) spectra of the Grown sample, which has one single SiGe epitaxy layer with the Ge fraction of 0.2. The channeling effect can be observed. The count ratio between the channeling spectrum and the random spectrum is only 7%. Thus, the SiGe layer is a single crystal with good quality.

In Fig. 3, two samples' Double Crystal X-Ray Diffraction (DCXRD) results are compared. One sample has been pre-cleaned at 750℃ for 5min, while the other has not. It is observed that the diffraction peak's width in Fig. 3(b) is narrower than in (a), as proves that the epitaxy layer's quality is improved due to the pre-clean.

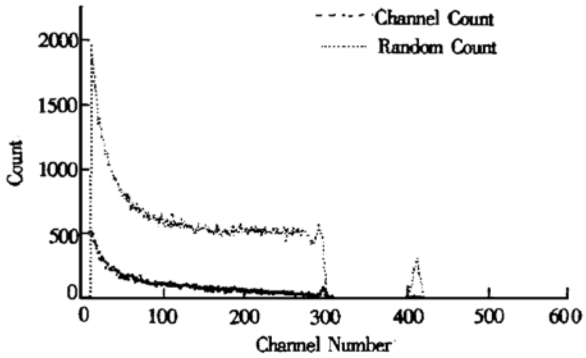

FIG. 2 RBS Spectra of Strain SiGe Epitaxial Layer

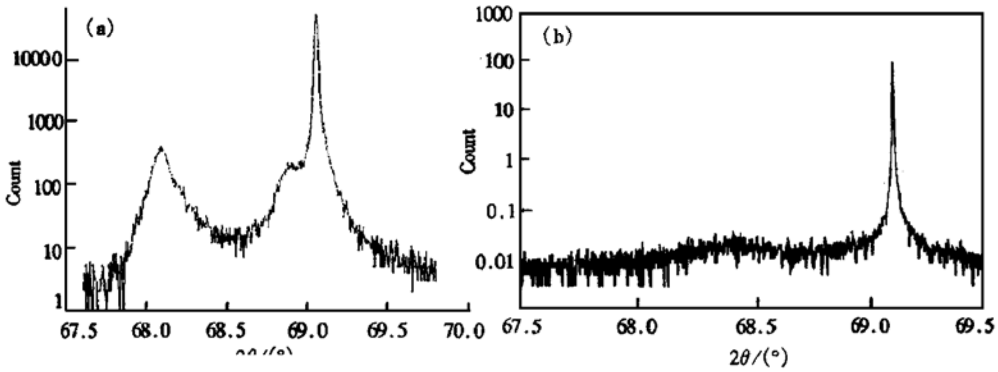

FIG. 3 Comparison of Two Samples DCXRD (a) with and (b) Without Pre-Clean Step

4 n-Si/i-p$^+$-i SiGe/n-Si Structure

The HBT has the structure of n-Si emitter/p$^+$-SiGe base/n-Si collector. The approach selected is blanket epitaxy plus mesa type transistor, i.e., the whole bare Si substrate is epitaxied with layers of Si and SiGe. The substrate is 4 inches in size, n$^+$ type, with resistivity of 0.001Ω·cm. The collector, base and emitter layers are doped to 1×10^{17}, 8×10^{18} and $2\times10^{18}cm^{-3}$, respectively. The base layer is about 100 nm in thick, with Ge fraction of 0.2, while the emitter layer is 250nm in thick. Because of the phosphorous blocking effect on the growth rate, it takes about 100min to grow. In addition, considering the strong self-doping and memory effects of phosphorous, we grow the collector layer first with the conventional epitaxy method.

Figure 4 is the Transmission Electron Microscope (TEM) image of the final structure. There are two dark zones between Si layers, which have proved to be the strained SiGe layers with Ge fractions being 0.2 and 0.03, respectively. The $Si_{0.97}Ge_{0.03}$ layer is used to prevent the boron diffusion from the base layer[6]. The lower Ge fraction cannot degrade the film stability much, but can weaken the influence of boron out diffusion by providing the band-gap grading. The interface is very flat, with no defects visible.

FIG. 4 TEM Image of Sample The dark zone is the strained SiGe layer.

Figure 5 is the Secondary Ionized Mass Spectrum (SIMS) result. The rising and falling edge are steep, because of the low temperature growth. The doping concentration transition is at a rate less than 10 nm/dec. All the boron is seen included in the SiGe region. Because the collector has a lower n type doping, the diffusion in the collector direction is more severe than that towards the emitter. Therefore, we grow the low fraction SiGe layer first, which is helpful to the enclosure of the boron dopant. The relatively gentle fraction slope will lower the intensity of the boron diffusion.

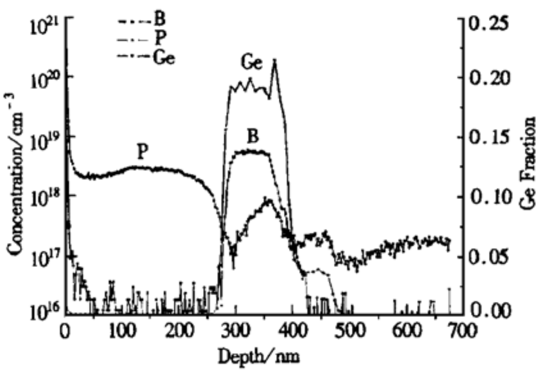

FIG. 5 SIMS Result of n-Si Emitter/p^+-SiGe Base/n-Si Collector The rising and falling edge is less than 10nm/dec.

The HBT with double mesa structure has been fabricated with the material grown in our system. It has good DC and microwave performance. And it is easy to make the current gain beyond 100. The Leakage current is less than $2nA/\mu m^2$. The cut-off frequency is 12.5GHz in a packaged form. The detailed result has been published before[7].

5 Conclusion

The strained SiGe material has been grown by using the self-developed High Vacuum/Rapid Thermal Process/Chemical Vapor Deposition (HV/RTP/CVD) system. Device-quality material has been obtained. The n-Si/i-p^+-i SiGe/n-Si structure was investigated and characterized by RBS, DXCRD, SIMS and TEM. The HBT with good performance is fabricated and acceptable for microwave applications. The simple equipment and process concerned is also adopted in industrial applications.

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采用高真空/快速热处理/化学气相淀积外延 SiGe HBT 结构*

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摘要: 采用新近研制的高真空/快速热处理/化学气相淀积 (HV/RTP/CVD) 系统生长了应变 SiGe 材料. 通过仔细设计的处理过程可以得到器件质量的材料. Ge 组分可以变化至 0.25, 可以得到控制良好的 n 型和 p 型掺杂层, 适用于异质结双极型晶体管(HBT)的制作. 研究了 SiGe HBT 的 n-Si/i-p$^+$-i SiGe/n-Si 结构. 所制作出的微波 HBT 性能良好, 证明了设备和工艺的水平.

关键词: 化学气相淀积; SiGe; HBT

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贾宏勇 博士生, 主要研究兴趣为 SiGe 材料生长、特性及其在微波 HBT 器件中的应用.

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