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Effect of Ti Silicidation on f_{max} and Base Resistance of SiGe Hetero-Junction Bipolar Transistors

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1. Introduction

The SiGe hetero-junction bipolar transistor (HBT) has been considered to be more suitable for RF integrated circuits (IC) than the Si bipolar junction transistor (BJT) because its electrical properties such as current gain, power consumption, and small-signal unity-gain frequency (f_T) are superior to those of the Si BJT [1]. Besides the f_T that should be high for the operation in RF range, the maximum oscillation frequency (f_{max}) must also be high for the application to digital circuit performance [2]. Since f_{max} is inversely proportional to the base resistance (R_B), the partial silicidation of the SiGe base layer may result in increase of f_{max}. In this presentation, the effect of Ti silicidation on f_{max} and base resistance of the SiGe HBT will be discussed.

2. Experimental

SiGe HBT's were fabricated with the sequence as shown in Fig. 1. The in-situ heavily doped SiGe base layer was grown in an atmosphere pressure/reduced pressure CVD system. Three kinds of devices were made with different conditions of Ti silicidation as shown in Table I. The base resistances in real devices were calculated from the sheet resistances of the as-deposited and silicided SiGe films. f_T and f_{max} were obtained using HP8510B network analyzer and UTMOST3 parameter extraction software.

3. Results & Discussion

Figure 2 represent the cross-sectional view and the plane view of the base and emitter region of the devices. Since the Ti silicide was formed after the patterning of the emitter layer, (a) region below the emitter remained the intrinsic base, and (b) region of the rest of the base converted to the extrinsic base. The resistances of the intrinsic base and the extrinsic base can hardly be measured from real devices. Therefore, the sheet resistances of the SiGe films as-deposited (R_{INB}) and silicided by the same process used for preparing the SiGe HBT (R_{EXB}) were obtained first. Due to the formation of $TiSi_2$, R_{EXB}'s were below 40% of R_{INB} as shown in Table II. Additionally, R_{EXB} abruptly changed with silicidation condition. In general, the two step annealing is performed for the formation of Ti silicide [3]. C49-$TiSi_2$ (60-70μΩ·cm) is formed during the first annealing at low temperature, and the phase transformation from C49-$TiSi_2$ to C54-$TiSi_2$ (15-20μΩ·cm) occurs in the second annealing at high temperature. Each annealing for device 1 performed at the temperature higher than that for device 2 or device 3 by 50°C resulted in very low value of R_{EXB}. This means that the $TiSi_2$ layer with low resistance applicable to the SiGe HBT is formed over the annealing temperature of 650°C and 850°C. Meanwhile, the thicker Ti layer pre-deposited before silicidation showed the lower R_{EXB} at the annealing temperature of 600°C and 800°C. The reason for the decrease of R_{EXB} with Ti thickness is attributed to be that the amount of $TiSi_2$ formed after silicidation is proportional to Ti thickness.

The base resistance in real devices can be calculated by simplification as shown in Fig. 2. Considering the areas of the intrinsic base and the extrinsic base, the total resistance of the base (R_B) is written as eq. (1)

$$\frac{1}{R_B}=\frac{2}{(3.7/0.8)R_{EXB}}+\frac{1}{(2.7/8.0)R_{EXB}+(1.0/8.0)R_{INB}} \tag{1}$$

Table II shows that the f_T and the f_{max} of real devices were improved with the decrease of the R_B calculated from eq. (1). Especially, the f_{max} sensitively varied with R_B. The f_T and the f_{max} of the bipolar junction transistor are generally given as eq. (2)-(3) [2].

$$f_T=\frac{1}{2\pi}\left(\frac{kT}{qI_c}(C_{EB}+C_{CB})+\tau_B+\tau_E+\tau_C\right)^{-1} \tag{2}$$

$$f_{\max}=\left(\frac{f_T}{8\pi R_B C_{CB}}\right)^{\frac{1}{2}} \tag{3}$$

where C_{EB} and C_{CB} are the emitter base and collector base capacitances, and τ_B, τ_E, τ_C are the base, emitter, collector transit times, respectively. Since f_T is inversely proportional to the sum of the τ_B influenced by R_B and other factors, it increases slightly with the decrease of R_B. However, the f_{max} which f_T and R_B directly affect grows rapidly with the reduction of R_B according to eq. (3). Table II clearly shows the f_T and f_{max} variation with R_B in this manner. Therefore, to improve f_{max} the base resistance of devices should be reduced. The linear relation between $\ln(f_{max})$ and $\ln(f_T/R_B)$ as shown in Fig. 3 indicates that the electrical characteristics of the devices prepared by Ti silicidation are compatible with eq. (3) and the previous calculation of the base resistance is reasonable.

4. Conclusions

The SiGe HBT with the f_T of 60.7 GHz and the f_{max} of 47.4 GHz was fabricated using Ti silicidation of the SiGe base layer. The base resistances in real devices were simply calculated from the sheet resistances of the as-deposited and silicided SiGe films, and the calculated values were consistent with measured f_T's and f_{max}'s. The f_{max} was drastically improved with the decrease of the base resistance originating from the Ti silicidation.

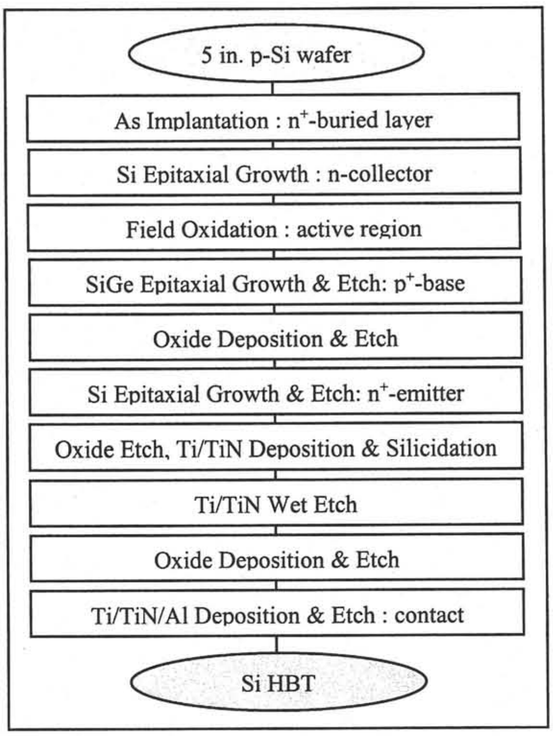

Fig. 1 SiGe HBT fabrication process.

Table I Ti silicidation conditions

Device	Ti/TiN thickness (nm/nm)	Temperature/Time (°C/sec)
1	20/20	650/10 + 850/30
2	30/20	600/30 + 800/30
3	20/20	600/30 + 800/30

Table II f_T, f_{max}, and R_B characteristics of SiGe HBT's (V_{CE} = 2V)

Device	f_T (GHz)	f_{max} (GHz)	R_{INB} (Ω/□)	R_{EXB} (Ω/□)	R_B (Ω/□)
1	60.7	47.4		22	45
2	40.0	15.2	3.10k	684	453
3	38.3	11.0		1232	638

Acknowledgments

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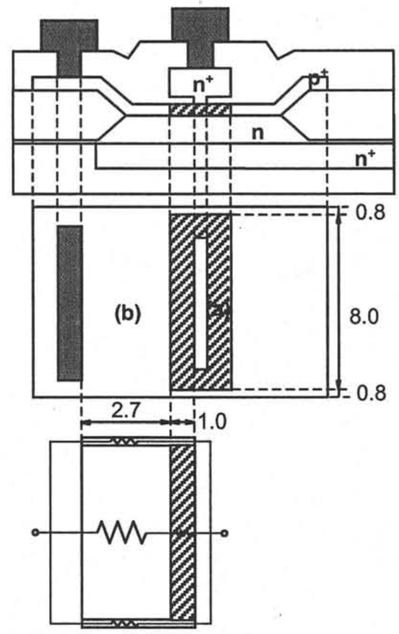

Fig. 2 Cross-sectional and plane views of the base and emitter region of a SiGe HBT.

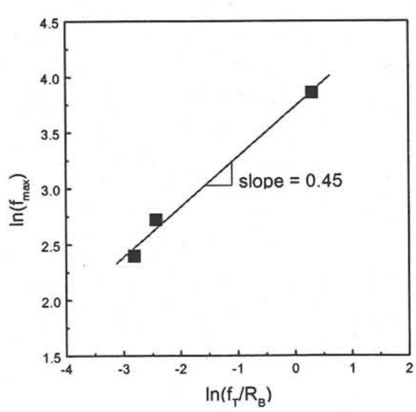

Fig. 3 $\ln(f_{max})$ vs $\ln(f_T/R_B)$.