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HCl-Free Selective Epitaxial SiGe Growth by LPCVD for 80-GHz BiCMOS Production

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1. Introduction

SiGe BiCMOS is the most promising candidate for microwave/millimeter-wave wireless communication systems and optical communication systems operating at 10 Gb/s and above. This is because high-speed digital circuits and high-frequency analog circuits can be obtained simultaneously. We have developed a high-performance SiGe HBT using selective epitaxial growth by UHV/CVD [1]. UHV/CVD has some advantages such as precise controllability of impurity profiles and a low growth temperature, however, the memory effect of the dopant in the chamber [2] and the low throughput are problems in mass-production.

In this study, we examine low-temperature HCl-free selective epitaxial SiGe growth by LPCVD for BiCMOS production. Although HCl is usually used to obtain growth selectivity for LPCVD [3][4], we do not use HCl, thus obtaining a sufficient growth rate at low temperature (660°C) and avoiding roughening of the growth surface at high boron doping concentrations. This technology has enabled us to manufacture SiGe BiCMOS with 80-GH f_T and 160-GHz f_{max} with sufficient throughput (20 min for one wafer).

2. Selective SiGe Growth by LPCVD

We used a lamp-heated commercial epitaxial growth chamber, in which the operating pressure was 1330 Pa with H_2 carrier gas, flowing at a rate of 20 l/min. Arrhenius plots for SiGe growth are shown in Fig. 1. The selective growth thickness was measured by cross-sectional SEM. A high growth rate improves throughput but degrades profile controllability. For our HBT, a growth rate of about 10 nm/min is required to simultaneously obtain sufficient throughput and profile controllability. Without HCl, this growth rate was achieved at 660°C, although with 40 ml/min of HCl, a temperature as high as 700°C was required.

Figure 2 shows the Ge concentration controllability. Two types of growth conditions were used: 660°C without HCl, and 700°C with 40 ml/min of HCl. The resulting Ge concentrations covered the range required for our HBT. The Ge concentrations were almost identical for the two growth conditions, since a higher growth temperature and a higher HCl flow rate have opposite effects on the incorporation of Ge in the grown layer.

The dependence of the boron concentration on the B_2H_6 flow rate is shown in Fig. 3. When the growth was carried out at 700°C with HCl, the growth surface became rough at high B_2H_6 flow rates as shown in the inset of the figure. This was caused by surface etching by HCl. Since surface roughening causes serious leakage between the emitter and base, this high concentration range cannot be used for HBTs. On the other hand, when the growth was carried out at 660°C without HCl, smooth surfaces were obtained up to a boron concentration of $5x10^{19}$ cm^{-3}. This enables us to use high-boron doping in the base region for high-performance HBT.

Figure 4 shows a plane view of a wafer surface after 70-nm selective growth without HCl at 660°C. We could not find any nuclei on the SiO_2, which meant that sufficient selectivity was obtained for the growth thickness for the base region of our HBT. This process utilizes the incubation time of the poly-SiGe growth on SiO_2 as in UHV/CVD.

3. HBT Performance

Self-aligned HBTs were fabricated using HCl-free selective SiGe growth at 660°C. A cross-sectional SEM image of the intrinsic region is shown in Fig. 5. The detailed fabrication steps were reported previously [1]. The selectively grown epitaxial layer structure consisted of three layers: intrinsic SiGe, boron-doped SiGe, and intrinsic Si. The SIMS profile of the selective epitaxial layer, which was grown in a 300x300-μm window, is shown in Fig. 6. The Ge concentration was changed in the boron-doped SiGe region, in order to accelerate electrons by the electric field resulting from the difference in the band gaps. The boron concentration was as high as $4x10^{19}$ cm^{-3}. There was no boron pileup at the interface, which is known to be one problem in UHV/CVD [2].

The thickness uniformity of the selectively grown layers was evaluated by SEM and is shown in Fig. 7. The width of the selectively grown layer was 0.2 um, which is identical to that of the HBT. The uniformity was 62±1 nm over a 200-mm wafer.

The Gummel plots of the HBTs are shown in Fig. 8. The HBT yield, measured from 10^4 parallel HBTs, was >99.9994%, which indicates that no defects were created in the selectively grown layer during fabrication process. The base current exhibited leakage at low V_{BE}, which was caused by tunneling due to the high-concentration emitter and base junction.

The cutoff frequency f_T and the maximum oscillation frequency f_{max} are shown in Fig. 9. The high-speed performances, 80-GHz f_T and 160-GHz f_{max}, were attributed to the thin, high-concentration base profile resulting from the low temperature, HCl-free epitaxial growth. The cutoff frequency was measured at five points on a wafer, as shown in the inset of Fig. 9. The high yield of HBTs and uniform f_T values together with high throughput show that the proposed selective epitaxial growth process can be applied to SiGe BiCMOS production.

4. Conclusion

Low-temperature HCl-free selective SiGe epitaxial growth technology for LPCVD has been developed. The high performance of the fabricated HBTs and the uniformity results showed that the process is suitable for SiGe BiCMOS production.

References

[1] K. Washio, et al., Tech. Digest of IEDM, p. 741, (2000).
[2] T. Hashimoto, et al., Tech. Digest of IEDM, p. 149, (2000).
[3] S. Ito, et al., J. Appl. Phys., 78, 2716, (1995).
[4] S. Bodnar, et al., J. Vac. Sci. Technol. B15, 712, (1997).

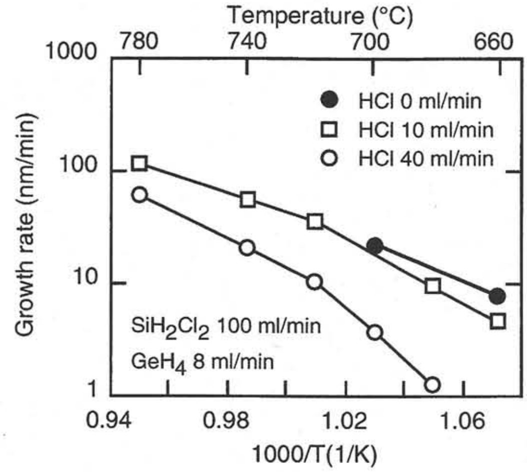

Fig. 1 Arrhenius plots for SiGe growth.

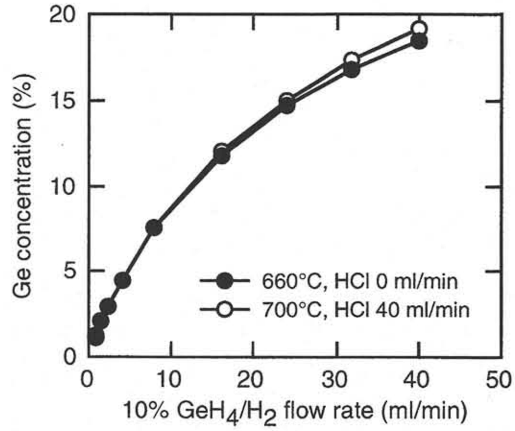

Fig. 2 Ge concentration.

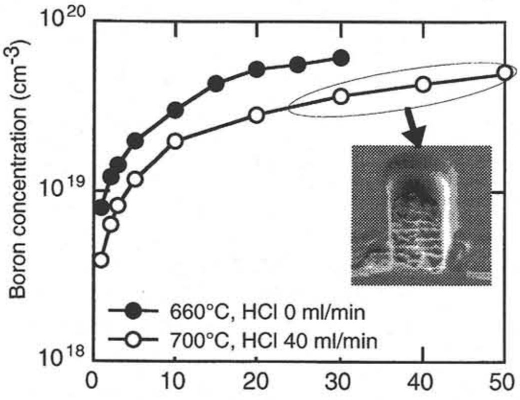

Fig. 3 Boron concentration.

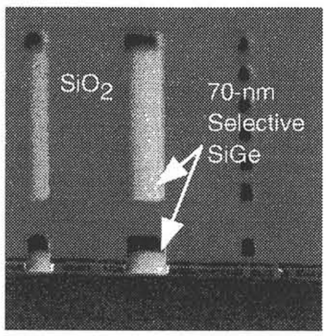

Fig. 4 Wafer surface after HCl-free selective SiGe growth.

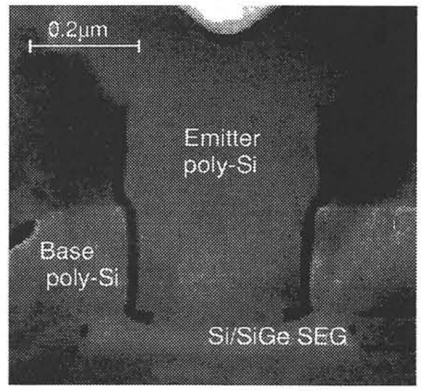

Fig. 5 Intrinsic region of HBT.

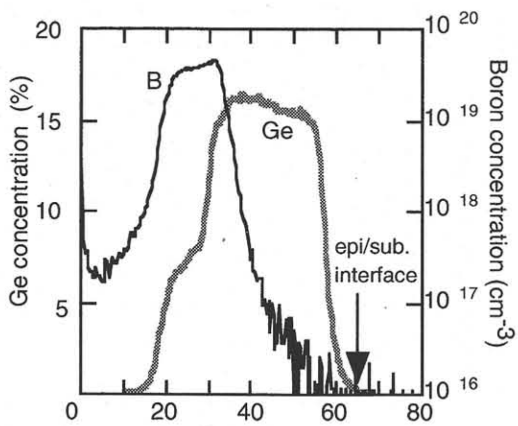

Fig. 6 SIMS profile of selectively grown layer.

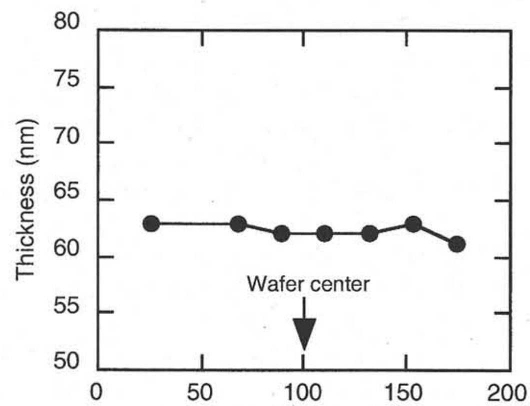

Fig. 7 Thickness uniformity of selectively grown layer.

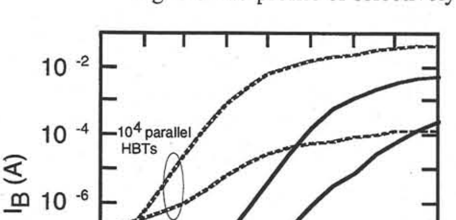

Fig. 8 Gummel plots of HBTs.

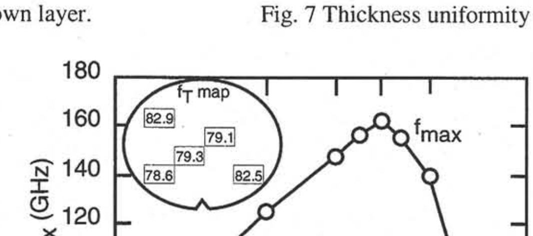

Fig. 9 Cutoff frequency and maximum oscillation frequency.

Table 1 HBT characteristics
A_E=0.2x1μm

h_{FE}	200
BV_{CEO} (V)	2.5
BV_{CBO} (V)	10.2
R_E (Ω)	27
R_B (Ω)	130
C_{JE} (fF)	3.0
C_{JC} (fF)	1.9
f_T (GHz)	80
f_{max} (GHz)	160