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94-GHz f_T, 0.4-dB NF_{min} HBT with Optimized Si-cap and Extrinsic Base using Blanket SiGeC Epitaxy for Consumer Wireless Applications

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1. Introduction

Recent advance in SiGe HBT BiCMOS technology has expanded the potential of silicon LSI to high frequency applications. These applications can be classified into two categories. One category includes tens of giga-bit wireline communication and millimetre wave applications in which very high-speed HBTs are used [1]. The other category is a consumer wireless electronics. In this case, BiCMOS process which can minimize the complexity to achieve short turn-around-time is required rather than extremely high-frequency characteristics [2]. Since these wireless systems operate at frequency of 2-5 GHz, the required f_T of HBT is in a range of 50 to 100 GHz.

We have developed 0.25-μm HBT BiCMOS for consumer wireless electronics. It uses LOCOS isolation and blanket SiGeC epitaxy, thus it has low-complexity [3]. In this paper, we describe the profile design of Si cap in SiGeC epitaxial layer to enhance the high frequency characteristics. The extrinsic base design, which includes link base implantation and cobalt silicidation, is also discussed. There are a lot of papers on the intrinsic profile optimization of HBT, however, we could hardly find simultaneous discussion on the intrinsic profile and the extrinsic base design. The optimized profile resulted in HBT with f_T of 94 GHz, and NF_{min} of 0.4 dB at 2 GHz and 0.7 dB at 5GHz, respectively.

2. HBT Structure and Profiles

A transmission electron micrograph of the emitter and base region of HBT is shown in Fig. 1. The base region is fabricated by blanket SiGeC epitaxy. The extrinsic base region is implanted with BF_2 just after patterning the emitter poly-Si. Then cobalt silicide is formed both on the extrinsic base and poly emitter. Typical Ge and boron profiles in epitaxial layer are illustrated in Fig. 2. The boron concentration in base region was 7 x 10^{19} cm^{-3}, and the as-grown base width was 5 nm. Thinner Si cap in the intrinsic region is necessary to make thin base layer which leads to higher f_T, however, poly-Si cap in the extrinsic region should be thick enough to avoid Ge and Co reaction, which causes highly resistive compounds [4]. So it is an important issue to optimize the Si cap of blanket SiGeC epitaxy for obtaining high f_T , low base resistance, and low noise figure.

3. Si Cap and Extrinsic Base Design

Si Cap Design

The cutoff frequency f_T of HBTs with different Si cap thickness was measured at V_{CE} of 1V and shown in Fig. 3. Thinner cap led to higher f_T due to thinner base width. The forward transit time, τ_F, was reduced from 2.1 ps to 1.8 ps when we changed the Si cap thickness from 45 to 35 nm. Since these HBTs have an identical collector profiles, this τ_F reduction is attributed to thinner base, i. e. reduction in the base transit time. The peak values of f_T and f_{max} are plotted as a function of Si cap thickness in Fig. 4. There is an optimum Si cap thickness of 40 nm for obtaining higher f_{max}. F_{max} is determined not only by the vertical profile but also by parasitic components in extrinsic base layer. The design of extrinsic base is described in the next section. Gummel plots of HBTs with different Si cap thickness are overlaid in Fig. 5. As the Si cap becomes thinner, the base current shows slightly leaky characteristics because the location of emitter and base junction becomes closer to the highly doped base region. However, the leaky characteristics of base current are not severe so that the HBT can be used in RF circuits. The breakdown voltages between emitter and collector were almost identical, 2.4 V, for these HBTs.

Extrinsic Base Design

The extrinsic base design includes BF_2 implantation and silicidation together with the Si cap. Figure 6 shows the dependence of an extrinsic base resistance R_{ext} and a collector capacitance C_{JC} on the extrinsic base implantation energy. The extrinsic base resistance was extracted by using dual base structure [5]. Higher implantation energy resulted in high C_{JC} and low R_{ext} due to deeply diffused boron. We found that HBT with 35-keV implantation energy showed the highest AC characteristics.

F_T and f_{max} of HBTs with different Co thickness are shown in Fig. 7. F_T is independent of the Co thickness, however, f_{max} is drastically improved by thicker cobalt layer. The sheet resistance of cobalt silicide layer was decreased from 6 to 3 ohm/sq. when the cobalt thickness was increased from 10 to 15 nm. A 15% reduction in R_{ext} was also observed. The combination of 40-nm Si cap and 15-nm Co has effectively reduced the sheet resistance without forming high resistive compound of Co and Ge.

The f_T and f_{max} characteristics for optimized HBT using above mentioned design of the Si cap and the extrinsic base are shown in Fig. 8. 94-GHz f_T and 81-GHz f_{max} were obtained at V_{CE} of 2 V. Noise figure was measured at 2 and 5 GHz as shown in Fig. 9. The minimum noise figures are 0.4 dB at 2 GHz and 0.7 dB at 5 GHz. Higher f_T and lower extrinsic base resistance resulted in NF_{min} reduction in half compared with that of control HBT without optimization. These characteristics show capability of the HBT to be used in consumer wireless applications.

5. Conclusions

The characteristics of SiGeC HBTs were described from the view point of the Si cap and the extrinsic base design. In accordance with the profile in the intrinsic region, the extrinsic base process was designed to obtain low resistance without forming highly-resistive compounds of Ge and Co. These design resulted in HBTs with 94-GHz f_T, 81-GHz f_{max}, 0.4-dB and 0.7-dB NF_{min} at 2 GHz and 5 GHz, respectively.

Acknowledgements

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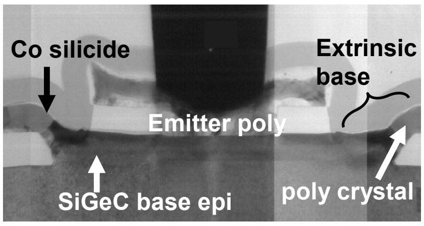

Fig. 1 TEM micrograph of emitter and base region of HBT.

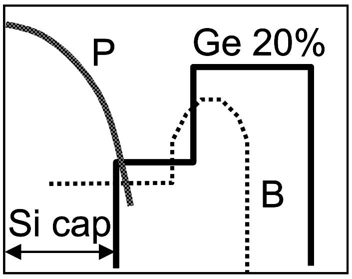

Fig. 2 Emitter and base profiles.

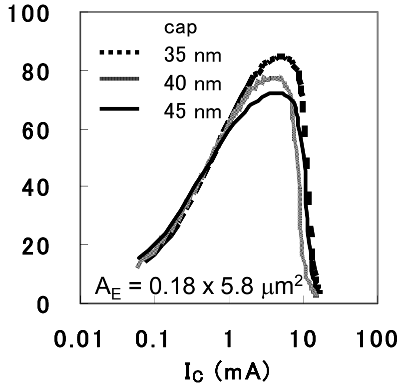

Fig. 3 F_T-I_C characteristics.

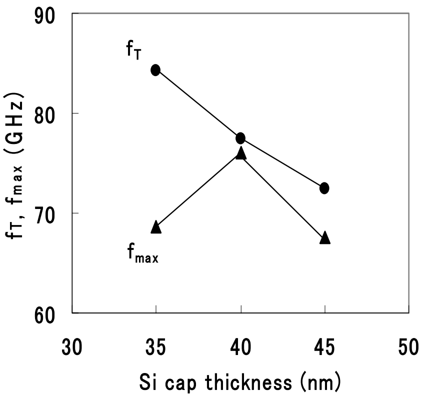

Fig. 4 F_T and f_{max} vs. Si cap thickness.

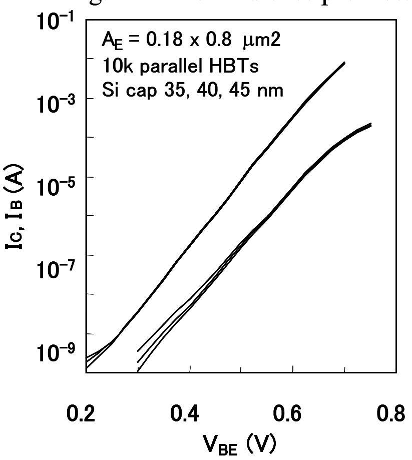

Fig. 5 Gummel plots of HBTs with different Si cap thicknesses.

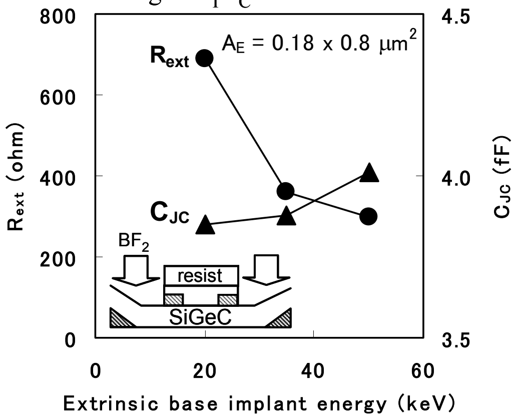

Fig. 6 R_{ext}, C_{JC} vs. extrinsic base implantation energy.

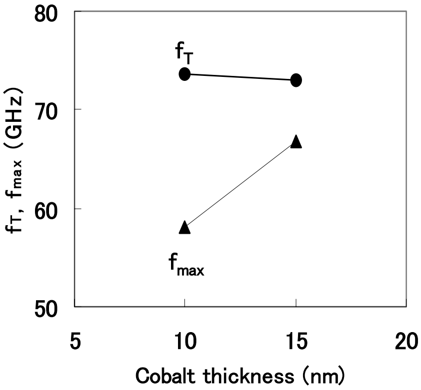

Fig. 7 F_T, f_{max} vs. Co thickness.

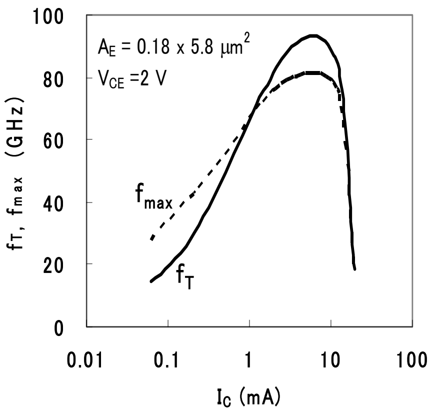

Fig. 8 F_T, f_{max} characteristics for optimized HBT.

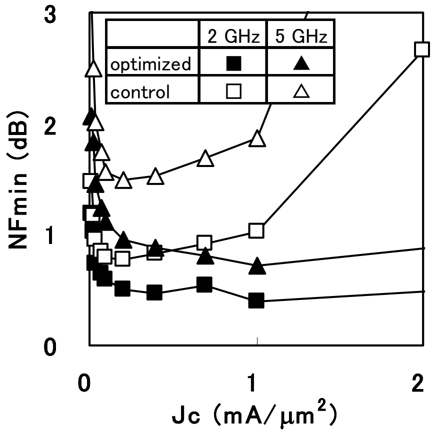

Fig. 9 Noise figure characteristics.