Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 288-289

E-3-2

Suppression of B outdiffusion by C incorporation in ultra-high-speed SiGeC HBTs

Katsuya Oda, Isao Suzumura, Makoto Miura, Eiji Ohue, Reiko Hayami,

Akihiro Kodama[1], Hiromi Shimamoto[1], and Katsuyoshi Washio

Central Research Laboratory, Hitachi, Ltd.,
1-280 Higashi-Koigakubo, Kokubunji, Tokyo 185-8601, Japan
Phone: +81-42-323-1111, Fax: +81-42-327-7764, E-mail: oda@crl.hitachi.co.jp
[1]Musashino Office, Hitachi Device Engineering, Co. Ltd., Kokubunji, Tokyo, Japan

1. Introduction

The SiGeC HBT has attracted much attention as a promising device for next-generation ultra-high-speed communication systems such as over-10-Gb/s optical communication systems, wireless LAN, and mobile communication systems. This is because C incorporation can suppress B outdiffusion during thermal processing [1] and reduce lattice strain in the $Si_{1-x}Ge_x$ layer [2]. Both high device performance and high reliability can therefore be achieved simultaneously. Although SiGeC HBTs have already fabricated [3][4], it can hardly be said that the effect of C incorporation into the SiGe base layer on the device performance has been sufficiently investigated. Accordingly, in the current work, we investigated the effect of C incorporation on B outdiffusion and on the AC characteristics of self-aligned SiGeC HBTs.

2. Experimental

An eight-inch Si (100) CZ wafer was used as a substrate. To achieve precise control of Ge, C, and B profiles and suppress the local loading effect, selective epitaxial growth of the $Si_{1-x-y}Ge_xC_y$ layer was performed by UHV/CVD. Disilane (Si_2H_6), germane (GeH_4), and methylsilane (CH_3SiH_3) were used as source gases, and dibolane (B_2H_6) diluted with hydrogen was used as a doping gas. Growth temperatures of the $Si_{1-x-y}Ge_xC_y$ layer and the Si cap layer were 556 and 575°C, respectively. These layers were selectively grown by utilizing the difference between incubation time of deposition on a Si substrate and that on a SiO_2.

3. Results

3.1 Suppression of B outdiffusion

To evaluate the outdiffusion, B diffusivities were derived from depth profiles measured by SIMS. All samples were annealed at 900°C after the epitaxial growth. The normalized B diffusivities in Si and $Si_{0.9}Ge_{0.1}$ layers at B concentration of 4×10^{19} cm^{-3} are shown in Fig. 1 as a function of C content. The diffusivity significantly decreases with C incorporation, and it becomes about 1/10 to that without C at the C content of 0.2%. Furthermore, since the B diffusivity in Ge is smaller than that of Si due to lattice strain, it also depends on the Ge content. Therefore, incorporation of both Ge and C is especially effective to suppress B outdiffusion. Normalized B diffusivity in SiGeC HBT as a function of B concentration is shown in Fig. 2. Although it is known that the B diffusivity in Si at high concentration increases with increasing hole concentration [6], the increase in B diffusivity is small in SiGe layer with C incorporation. These results indicate that B outdiffusion in the SiGe base layer can be sufficiently suppressed by C incorporation even at high B concentration.

3.2 Characteristics of SiGeC HBTs

A schematic cross-section of a self-aligned HBT is shown in Fig. 3. The SiGeC collector, the p-SiGeC base with a Ge content of 10%, and the Si cap layers were epitaxially grown only on the single Si layer and the base poly-Si. Doping concentration in the base layer was varied from 4×10^{19} to

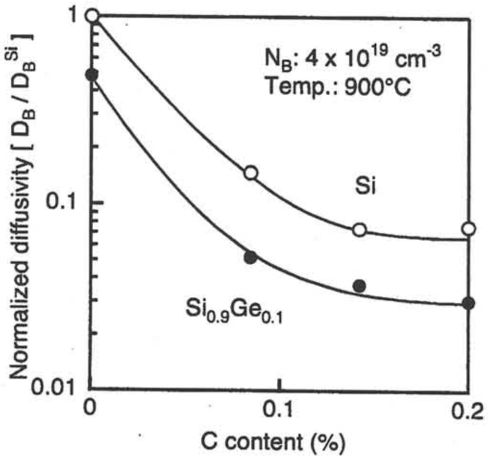

Fig. 1 Normalized B diffusivity in SiGeC layer as a function of C content.

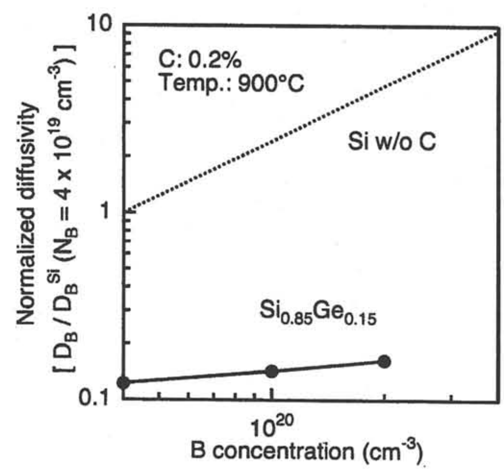

Fig. 2 Normalized B diffusivity in SiGeC HBT as a function of B concentration. Dotted line indicates B diffusivity in Si without C incorporation [6].

8×10^{19} cm^{-3}. To form the SiGeC HBT, C was incorporated around the base and collector layer at a content of 0.2%. After the epitaxial growth, a selective ion-implanted collector was formed by P implantation through the epitaxial SiGeC layer, then the emitter was formed by P diffusion from in-situ doped poly-Si (IDP) by RTA at 900°C for 30 s.

SIMS profiles of B in SiGe and SiGeC epitaxial layers are shown in Fig. 4. The B profile in the SiGe layer is broad because of the outdiffusion caused by the high-temperature processing such as the emitter formation. On the other hand, since the B outdiffusion was suppressed by the C incorporation, a shallow base layer with high B concentration can be formed in the SiGeC layer.

Cutoff frequency (f_T) and base resistance ($r_{bb'}$) of the SiGe HBTs are shown in Fig. 5 as a function of collector current. Although f_T increases with reducing base width, $r_{bb'}$ of a HBT with a base width of 5 nm becomes considerably higher than that corresponding to 10 nm. This result indicates that base Gummel number decreases with decreasing base width. In other words, the carrier concentrations are compensated at emitter-base and collector-base junction due to the B outdiffusion. Figure 6 shows f_T and $r_{bb'}$ of a SiGeC HBT with a base width of 4 nm at a B concentration of 1×10^{20} cm^{-3}. In this figure, the characteristics of a SiGe HBT, which are the same values given in Fig. 5, are also plotted. It is clear that f_T is significantly increased by C incorporation, and its peak value is 165 GHz. Moreover, as a result of keeping the profile of high B concentration, base resistance is quite low even at the small base width. These results clearly indicate that the C incorporation can produce a shallow base with high B concentration.

4. Summary

We investigated the effect of C incorporation on the performances of self-aligned SiGeC HBTs fabricated by UHV/CVD. A shallow base was produced by suppressing B outdiffusion. Consequently, low base resistance and high cutoff frequency of 165 GHz were achieved. These results demonstrate the advantages of C incorporation in a self-aligned HBT for future ultra-high-speed communication systems.

References

[1] H. Rücker et al., IEDM Tech. Dig., p. 345, 1999.
[2] S. Sego et al., J. Vac. Sci. Technol. A14, p. 441, 1996.
[3] K. Oda et al., IEDM Tech. Dig., p. 741, 2001.
[4] S. J. Jeng et al., IEEE Electron Device Lett., 22 (2001) p. 542.
[5] K. Washio et al., Tran. on Electron Devices, 49 (2002) p. 271.
[6] R. B. Fair, J. Electrochem. Soc., 122 (1975) p. 800.

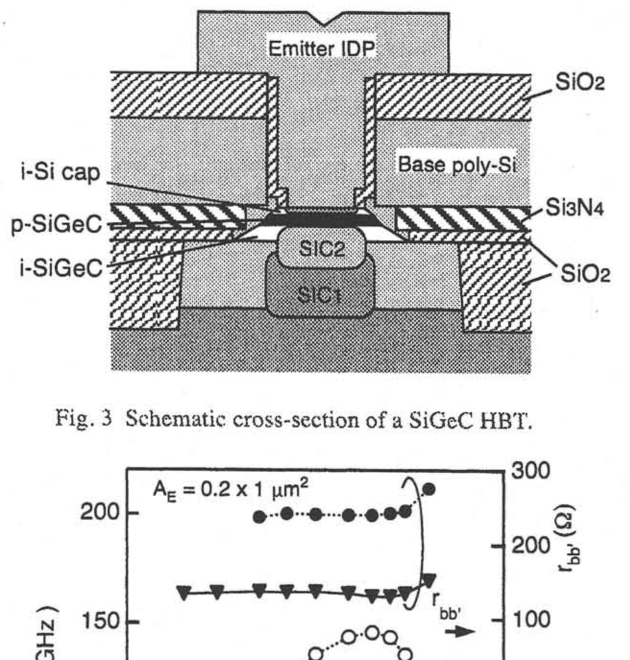

Fig. 3 Schematic cross-section of a SiGeC HBT.

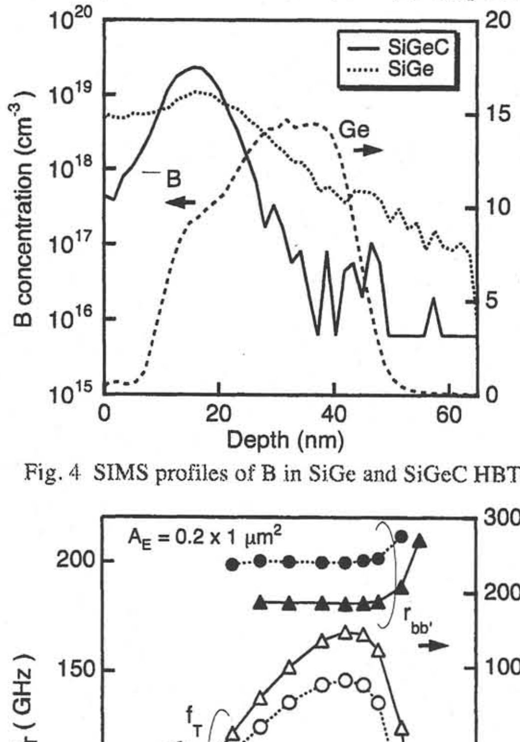

Fig. 4 SIMS profiles of B in SiGe and SiGeC HBTs.

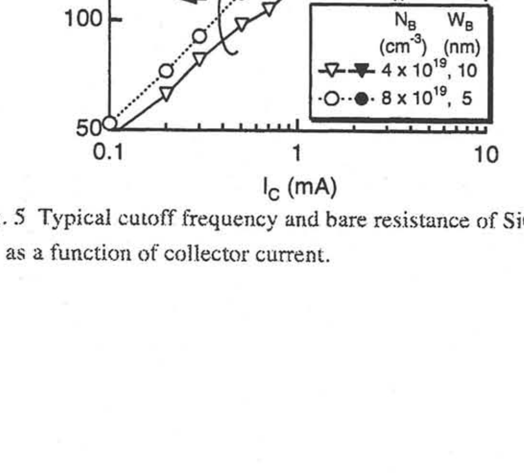

Fig. 5 Typical cutoff frequency and bare resistance of SiGe HBTs as a function of collector current.

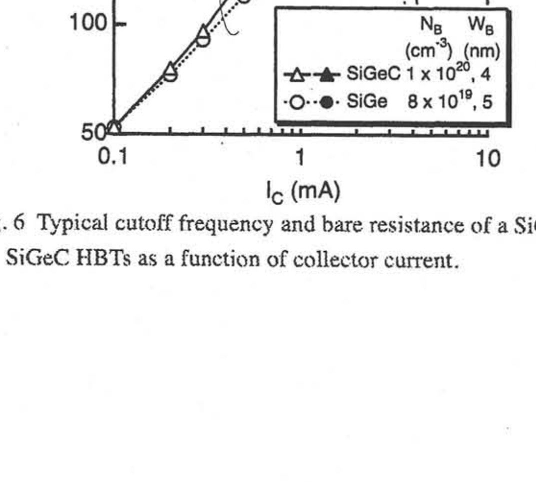

Fig. 6 Typical cutoff frequency and bare resistance of a SiGe and SiGeC HBTs as a function of collector current.