Cl_2 Influence on $Si_{1-x}Ge_x$ Base Epitaxial Layer Growth for High Speed Bipolar Transistor

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1.Introduction

Si_{1-x}Ge_x selective epitaxial growth is one of the most important technologies in fabricating high speed bipolar devices, especially for super self-aligned selectively grown base (SSSB) transistors^{1),2)} by ultra-high vacuum chemical vapor deposition (UHV-CVD) using Si₂H₆ and GeH₄. A graded Si_{1-x}Ge_x base layer, in which the Ge content increases form the emitter-side toward the collector side, is connected with the base poly-silicon electrode in the tunnel which overhangs the Si substrate. In order to increase the cut-off frequency f_T, Si_{1-x}Ge_x base layer thickness should be reduced. However, thinner Si_{1-x}Ge_x base layer induces the difficulty in the contact of the base layer with the base poly-silicon (Fig. 1). Therefore, the base layer thickness is limited by this contact formation.

In this study, we have demonstrated that the epitaxial layer becomes thicker only in the tunnel when Cl_2 is incorporated during growth at low temperature, and the mechanism is also reported from the point of $Si_{1-x}Ge_x$ growth with Cl_2 gas. Using this method, thinner $Si_{1-x}Ge_x$ base layer can be formed with an edge rising structure resulting the higher f_T of 70GHz.



Fig.1. Schematic view of base structure in SSSB transistor before (a) and after base growth (b).

2. Experimental procedure

The epitaxial layers were grown on Si(001) substrates in a cold-wall type UHV-CVD chamber with the base pressure below $2X10^{-7}$ Pa. Prior to the growth, the Si substrates were cleaned with the mixture of ammonia and peroxide solutions, and then annealed at 910°C in the UHV-CVD chamber. Si₂H₆ and GeH₄ gases for the SiGe epitaxial growth and Cl₂ gas for selective growth were irradiated to the substrate coincidentally in the temperature range of 550-750°C.

Figure 1 shows the base structure in SSSB transistor, having tunnel structures consisting of base poly-silicon overhanging n⁻-Si (001) substrate. The Si_{1-x}Ge_x base epitaxial layer was selectively grown on the Si substrate. The tunnel height was about 100nm, and the Si_{1-x}Ge_x base layer was about 65-75nm.

Results and discussion

Since addition of Cl₂ gas in UHV-CVD is very effective to improve selectivity^{2),3)}, Cl₂ gas was used for the Si_{1-x}Ge_x epitaxial layer formation in the tunnel. The time for silicon nucleation on SiN mask became five times longer by the Cl₂ addition. Figure 2 shows the cross-sectional SEM images of the Si1-xGex layers with and without Cl₂. An edge rising structure can be observed only in the epitaxial layer grown with Cl₂ gas, although uniform base layer is formed without Cl₂ gas. To clarify the Cl₂ influence, Arrhenius plot of Si_{1-x}Ge_x epitaxial growth rate with and without Cl₂ gas is shown in Fig. 3. There is no influence of Cl₂ addition on the growth rate at higher temperature, suggesting that Cl atoms desorb from the growing surface without etching. On the other hand, the extreme reduction of the growth rate can be observed at lower temperature when Cl₂ gas is incorporated. The growth does not occur below 560°C.



Fig. 2. Cross sectional SEM image of Si_{1-x}Ge_x epitaxial layers without (a) and with Cl₂ addition (b).



Fig. 3. Arrhenius plot of $Si_{0.91}iGe_{0.09}$ epitaxial growth rate with and without Cl_2 addition.

The good agreement is obtained between the growth stop temperature of 560°C with Cl_2 addition in this work and HCl desorption temperature of 580°C in the TPD study⁵⁾. This supports that the growth rate in Cl_2 addition is limited by the HCl desorption in the low temperature regime, and the small HCl desorption rate compared with H_2^{60} causes the reduction of the growth rate by Cl_2 addition.

The reason of the formation of the edge rising structure is considered as follows: The sticking coefficient of Cl_2 gas is so high that Cl_2 atoms are consumed in the tunnel by the collisions to the wall around the tunnel as a result, the concentration of Cl_2 gas becomes lower according to increase in the distance from the tunnel entrance. This Cl_2 distribution is considered to cause the film thickness increasing in the tunnel, resulting the edge rising structure.



Fig. 4. Cross sectional SEM image of Si_{1-x}Ge_x epitaxial layers. The growth temperature was 715℃ (a), 690℃ (b), 665℃ (c) and 640℃ (d).

The difference between the growth rate with and without Cl_2 gas is important for the tunnel filling. Figure 4 shows the dependence of the $Si_{1-x}Ge_x$ layer structure in the tunnel on the growth temperature. The edge rising does not occur at the temperature higher than 690°C, because the growth rate by Cl_2 addition is not reduced in Fig. 3. The temperature decreasing is very effective for the edge rising and filling the tunnel structure. The tunnel can be filled with the graded $Si_{1-x}Ge_x$ base layer at the growth temperature of 640°C, as shown in Fig. 5. By decreasing the growth temperature from 640 to 605°C, the thickness of the graded $Si_{1-x}Ge_x$ base layer can be reduced from 75 to 65nm with the tunnel filling. The f_T of the device was increased from 50 to 70GHz with excellent base contact.



Fig. 5. Cross sectional SEM image of the graded Si_{1-x}Ge_x base structure in the SSSB transistor.

4.Conclusions

We investigated the influence of Cl_2 addition on the $Si_{1-x}Ge_x$ epitaxial growth in the tunnel structure by UHV-CVD using Si_2H_6 and GeH_4 . The rising of $Si_{1-x}Ge_x$ layer in the tunnel is considered to be caused by the decrease in the Cl_2 concentration according to the distance from the tunnel entrance. The thin $Si_{1-x}Ge_x$ base layer of 65nm can be formed at low growth temperature of 605 °C with Cl_2 gas, resulting the excellent performance in bipolar transistor.

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