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Strong impact of slight misalignment of the trench direction from [11-20] on deep trench filling epitaxy for SiC super-junction (SJ) devices

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Abstract

Trench filling epitaxial growth technique by hot-wall CVD including HCl gas has been developed for SiC super-junction (SJ) devices. Deep p/n columns over 10µm is needed for 3-6kV class devices but has not been established. A slight misalignment of the stripe trench direction from [11-20] was found to make a strong impact on growth direction of the mesa top epilayer. The small misalignment decreased the filling rate at the trench bottom and resulted in the trench fast closing. The 25-µm-deep trench backfilling was successfully demonstrated by use of the wafer with a high O. F. accuracy.

1. Introduction

Super-junction (SJ) structures have been developed in order to push beyond the limit of unipolar power devices [1]. Si-SJ devices are now widely used up to 1kV-class, and the same impacts are also expected in the SiC devices. Basically, the impact of SJ structure becomes prominent with increasing blocking voltage, however, its manufacturing becomes increasingly difficult. The SJ structure on 4H-SiC was successfully fabricated by using a multi-epitaxial growth method, and the effect of SJ structure was confirmed experimentally [2, 3]. Although the method can be applied to the 1.2kV-class devices, it is not practical to form deep p/n columns, because the number of epi-growth and ion implantation becomes too much. Alternately, the trench-filling epitaxy is expected to be used in the wide voltage range applications [4, 5]. We reported the fabrication of 7-µm-deep p/n columns by CVD using $SiH_4/C_3H_8/H_2$ gases [4], but the growth reproducibility was poor. Meanwhile, on the trench filling over 10-µm-deep by CVD including HCl gas, the growth becomes significantly stable [6], however, the trench fast closing has been observed frequently. We speculate that the trench fast closing is caused by the misalignment between the trench direction and the off direction of SiC wafer (i.e., [11-20] direction).

In this study, we challenge a deep trench filling epitaxial growth over 20 µm on (0001) 4H-SiC by focusing on deviation of the trench direction from [11-20] so as to suppress the void formation before the completion of trench filling.

2. Experimental

Trench filling epitaxial growth

A horizontal hot-wall CVD system equipped with standard precursors and gases, silane (SiH_4), propane (C_3H_8) and trimethylaluminium (TMA) was employed. The source gases, SiH_4 and C_3H_8 were supplied at C/Si =1. HCl gas was added to the growth in order to suppress the mesa top growth significantly to avoid void formation [6]. The growth temperature was 1650 °C and the growth duration was 3-6 hours. The scanning electron microscope (SEM) was used on the observation of cross-sectional images of each type of trench to estimate thickness distribution and growth rate of epilayer.

Tilted stripe trenches

To examine the impact of deviation of the trench direction from [11-20] in detail, the trench mask patterns on photolithography were intentionally tilted from -2 ° to 2 ° (= θ_{trench}) at 0.5 ° steps as shown in Fig. 1. The 0 ° of the mask pattern is almost exactly coincident with the direction of orientation flat (O. F.) of the wafer, because the wafer stage of photolithography machine has sufficiently high accuracy. On the other hands, the direction of O. F. does not mean the same as the [11-20] direction. The direction of O. F. must be affected by an error in the wafer manufacturing process. That is, there is a slight deviation of trench direction from [11-20] direction. A nine types of trenches was formed on 4° off oriented n-type (0001) 4H-SiC wafer by an inductively coupled plasma (ICP) etching. The line (L) and space (S) width are both 2.25-2.5 µm, and the depths (D) are 22~25 µm.

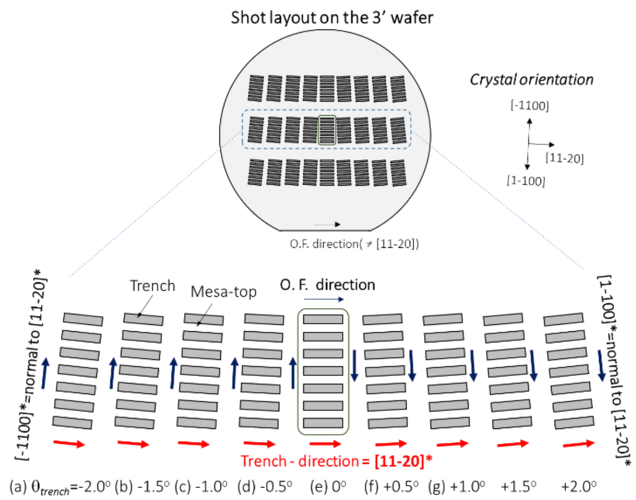
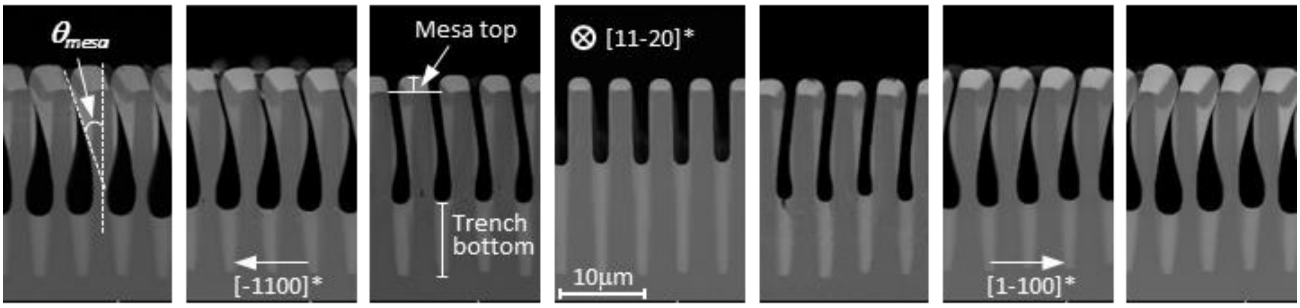


Figure 1. Shot layout on the 3-inch wafer and a schematic of intentionally tilted nine types of trenches on photo mask. The direction at (e) θ_{trench} = 0 ° corresponds to the O. F., which is not exactly the same as [11-20] crystal orientation. The [11-20]* means the trench direction on each L-S pattern. The [-1100]* and [1-100]* directions are perpendicular to [11-20]* (These two opposite directions imply the tilt direction of mesa top epilayer described below.).



(a) θ_{trench}=-2.0° (b) -1.5° (c) -1.0° (d) -0.5° (e) 0.0° (f) +0.5° (g) +1.0°

Figure 2. Cross-sectional SEM images after 3 hours backfilling epi-growth to the intentionally tilted nine types of trenches on the same wafer. Notation of (a) to (g), and definitions of the [1-100]*, [-1100]* and [11-20]* directions on each mask pattern are the same as those of Fig. 1. Each sample was individually cut perpendicular to the [11-20]* for the observation.

3. Results and discussion

Figure 2 shows cross-sectional SEM images after trench-filling for seven trenches, denoted as (a) to (g) in Fig. 1, respectively. Tilt angle of the grown epilayer on mesa top (= θ_{mesa}) for each trench was measured, and the angle is found to be strongly depended on the trench direction on mask patterns, θ_{trench}. The growth direction on mesa top is close to the surface normal at θ_{trench} = -0.5 °, suggesting the O. F. direction was deviated by 0.5 ° from [11-20] direction on the original wafer. The θ_{mesa} of (a) to (c), and that of (e) to (g) tilts toward [-1100]* and [1-100]*, respectively, and the θ_{mesa} becomes increasingly larger as the θ_{trench} increases. The series of θ_{mesa} are summarized in Fig. 3(a) as a function of the θ_{trench}. Figure 3(a) clearly demonstrates a linear correlation between the θ_{trench} and θ_{mesa}. Slope of the fitted line is estimated to ~13, which indicates a slight deviation of the trench direction from [11-20] is amplified more than 10 times. Growth rates at the trench bottom (= GR_tb) and mesa top (= GR_mt) were summarized in Fig. 3(b). The GR_tb shows the maximum at θ_{trench} = -0.5 °, while the GR_mt shows minimum value at the same angle. This suggests that a precise control of the trench direction is important for the efficiency of trench filling growth as well as suppressing void formation.

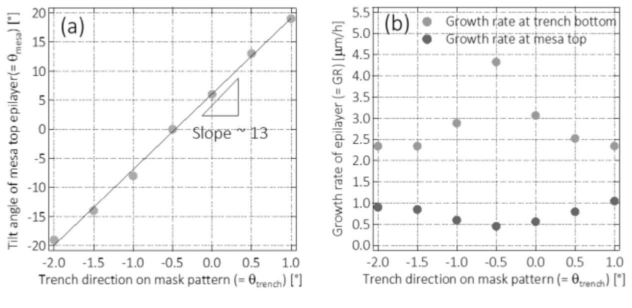


Figure 3 (a) Dependence of the θ_{mesa} (= tilt angle of the grown epilayer on mesa top) on the θ_{trench} (= trench direction on mask pattern). (b) Dependence of the growth rate at the trench bottom and mesa top on the θ_{trench}.

Finally, we performed the backfilling epitaxial growth to the 25-μm-deep trench using the selected wafer with a high O. F. accuracy. The growth condition was the same as that in Fig. 2. Figure 4 shows the cross-sectional SEM image after epi-growth. The 25-μm-deep trench was successfully filled by 6 hours growth without void formation, where the GR_tb is estimated to be over 4μm/h. From the measured θ_{mesa}= 1 °, deviation of the trench direction was estimated to be ~0.1 °. This suggests that the trench direction has to be controlled with the ~0.1 ° accuracy on deep trench backfilling.

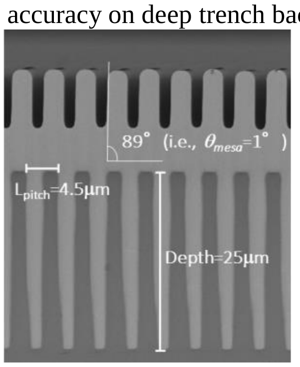


Figure 4. Cross-sectional SEM image of 25-μm-deep trench after backfilling epi-growth using a wafer with high O. F. accuracy.

4. Conclusions

By using various tilted trenches formed on the same wafer, a linear correlation between the growth direction on mesa top and trench direction was confirmed. A slight deviation of trench direction from [11-20] invokes a large tilted growth on mesa top by a factor of more than 10. Twenty-five-μm-deep trenching and backfilling were successfully demonstrated by use of the wafer with a high O. F. accuracy. We believe that a precise control of the stripe trench direction is indispensable for the deep trench backfilling on SiC.

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