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Growth and investigation of stacking fault of 4H-SiC C-face homoepitaxial layers with 1° off-angle

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Abstract

We grew epitaxial layers on 4H-SiC C-face substrates with 1° off-angle and studied about the stacking faults (SFs). We found that 3C-inclusion, 8H-SF and (3,5)-SF were generated in grown epitaxial layers. These SF densities were not changed by varying the C/Si ratio and only 3C-inclusion density was decreased by *in-situ* etching. It is thought that 3C-inclusion was caused by 3C-SiC particles fallen on substrates before and during growth. Moreover, 8H- and (3,5)-SF densities were found to correlate with shallow pit density.

1. Introduction

4H-SiC is expected to be widely used for power devices because of certain physical properties such as a wide bandgap and high thermal conductivity. Recently, the trench structure devices have been necessary for reducing the on-resistance. However, these devices have anisotropy of device properties such as channel mobility and threshold voltage due to use of substrates with large off-angle such as 8° and 4° [1]. Moreover, reliability of these devices should be improved [2]. It has been reported that lowering the off-angle is effective for suppressing the anisotropy of device properties [1] and the reliability is improved by using C-face substrates [2]. For this reason, 4H-SiC homoepitaxial growth on C-face substrates with lower off-angle than 4° is potential candidate to improve the trench structure device properties.

For device applications of the C-face epitaxial layers with lower off-angle, decrease of background carrier concentration and stacking fault (SF) density is extremely important. Concerning background carrier concentration, for example, the order of 10^{14} cm^{-3} is required for 3.3 kV MOSFET because the requirement for the drift layer carrier concentration is around 3×10^{15} cm^{-3}. It has been reported that the background carrier concentration of C-face epitaxial layers can be reduced to the order of 10^{14} cm^{-3} by increasing C/Si ratio due to site competition effect even though residual nitrogen incorporation of C-face epitaxial layers is more intense than that of Si-face epitaxial layers [3, 4, 5]. Concerning SF, the negative effects on device properties are increased by lowering the off-angle because of increase in the area of SF. However, there is no report about SF in the C-face epitaxial layers with lower off-angle.

In this study, we grew epitaxial layers on 4H-SiC C-face substrates with 1° off-angle and investigated SF densities for the C/Si ratio and *in-situ* etching time. Moreover, we characterized the SF.

2. Experimental Procedures

Epitaxial growth was performed on 4-inch 4H-SiC C-face substrates with 1° off-angle in a horizontal hot-wall CVD system. H_2 was used as the carrier gas, and SiH_4 and C_3H_8 were used as the precursors. Growth rate was 3.5 - 4.5 μm/h. Both temperature of *in-situ* H_2 etching and growth were 1725 °C. We varied the C/Si ratio from 0.8 to 2.0 in order to confirm a decrease of the background carrier concentration and to investigate effects on the SF density. In addition, *in-situ* etching time was varied from 0 min to 60 min because *in-situ* etching might affect the SF density due to removal of particles on substrates.

The thickness and background carrier concentration were measured using FT-IR and *C-V* measurements, respectively. Surface morphology was characterized using AFM. The defect characterization was performed using SEM, confocal microscope with a differential interference contrast (CDIC) system and PL.

3. Results and discussion

Firstly, we studied about the uniformity of the thickness and carrier concentration, and surface morphology of 4-inch C-face epitaxial layers with 1° off-angle to confirm that these properties are acceptable for device applications. There was little change in these properties when the C/Si ratio and *in-situ* etching time were varied, and all epitaxial layers have a good uniformity and smooth surface. The typical uniformity of the thickness and carrier concentration was 1-2% and 10-15% (σ/mean), respectively. RMS values were less than 0.2 nm and step bunching was not generated. It indicates that surface steps of C-face hardly bunch even when the off-angle is low at 1° due to its low surface energy [4].

Secondly, we confirmed the decrease of the background carrier concentration, and investigated effects on the SF density by varying the C/Si ratio. In this experiment, *in-situ* etching time was 10 min. With increasing the C/Si ratio from 0.8 to 2.0, the background carrier concentration decreased from 2.1×10^{15} cm^{-3} to 5.2×10^{14} cm^{-3} supposedly due to the site competition effect [5]. We consider that this background carrier concentration grown at the C/Si ratio of 2.0 is acceptable for 3.3 kV MOSFET. In these epitaxial layers, we observed three types of SFs identified as

3C-inclusions, 8H-SF and (3,5)-SF from PL measurements [6]. We found that these SF densities were not affected by the C/Si ratio. 3C-inclusion density was less than 0.2 cm^{-2} and each 8H- and (3,5)-SF densities were less than 0.1 cm^{-2} regardless of the C/Si ratio. It has been reported that triangle defects, which might be some kind of SFs, frequently generate at too high C/Si ratio [7]. It seems that the SF density exponentially increases if the C/Si ratio increases to over 2.0. At least, these SF densities were not changed in this C/Si ratio range from 0.8 to 2.0.

Thirdly, we investigated effects of varying the *in-situ* etching time on the SF density. The C/Si ratio was 2.0 to control the background carrier concentration to minimum level. 3C-inclusion, 8H-SF and (3,5)-SF were observed also in this experiment. Fig. 1 shows these SF densities for the *in-situ* etching depth or *in-situ* etching time. Note that these SF densities are higher than the densities of the experiment of varying the C/Si ratio shown in the last paragraph due to a difference of chamber conditions and substrate quality depending on boule. The *in-situ* etching depth was estimated from the etching rate of epitaxial layers because it is difficult to directly measure the etching depth of substrates. 3C-inclusion density approximates 0.5 cm^{-2} when the *in-situ* etching depth is over 0.4 μm, though the density is 1.6 cm^{-2} when the depth is 0.1 μm as shown in Fig. 1. We found that the 3C-inclusion density is decreased by *in-situ* etching. In contrast, the 8H- and (3,5)-SF densities are approximately 0.5 cm^{-2} regardless of the *in-situ* etching depth. Therefore, it is obvious that 8H- and (3,5)-SF densities are not affected by *in-situ* etching.

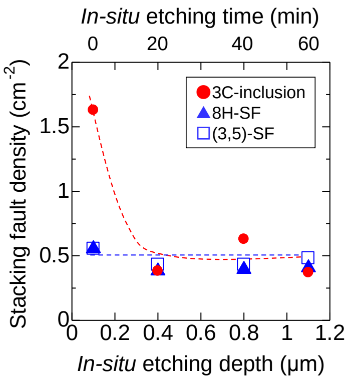

Fig. 1 SF densities for the *in-situ* etching depth or *in-situ* etching time.

Lastly, we researched the origin of these SFs. We found that there was a particle at a starting point of 3C-inclusions by using SEM measurements. Other papers have reported that the cause of 3C-inclusions is 3C-SiC particles in Si-face epitaxial layers with large off-angle [8, 9]. It suggests that the cause of 3C-inclusions is 3C-SiC particles regardless of the off-angle and the polar face. It is thought that the 3C-inclusion density in Fig. 1 increases in the case of the *in-situ* etching depth of 0.1 μm due to lack of removal of particles on substrates before growth. Moreover, it seems that particles fall from somewhere, such as the susceptor, on substrates during growth because the 3C-inclusion density is constant at the *in-situ* etching depth of over 1 μm. In contrast, we found that 8H- and (3,5)-SF had a shallow pit not a particle at their starting point by using CDIC. It is thought that the origin of 8H- and (3,5)-SF is the shallow pit. Then, we investigated relationship between the 8H- and (3,5)-SF densities and the shallow pit density as shown in Fig. 2. It is obvious that 8H- and (3,5)-SF densities correlate with shallow pit density. We found that it is important to decrease the shallow pit density for decreasing the 8H- and (3,5)-SF densities. More details about the origin of 8H- and (3,5)-SF will be presented at the conference.

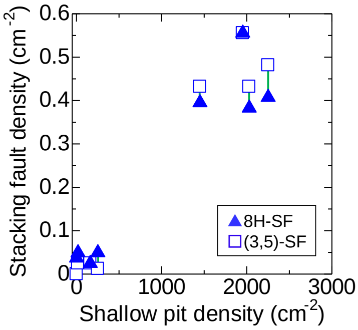

Fig. 2 Relationship between the 8H- and (3,5)-SF densities and the shallow pit density.

4. Conclusions

We grew epitaxial layers on 4H-SiC C-face substrates with 1° off-angle and studied about the SFs. We found that 3C-inclusion, 8H-SF and (3,5)-SF were generated in grown epitaxial layers. These SF densities were not changed by varying the C/Si ratio. The 3C-inclusion density was decreased, and 8H- and (3,5)-SF densities were not affected by *in-situ* etching. It is thought that the origin of 3C-inclusion is 3C-SiC particles fallen on substrates before and during growth. In addition, we found that it is important to decrease the shallow pit density for decreasing the 8H- and (3,5)-SF densities.

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