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Control of Defect Formation in 4H-SiC Films Using Surface C/Si Ratio by High Speed Wafer Rotation Vertical CVD

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Abstract

Surface C/Si ratio was demonstrated as a useful indicator for the control of defect formation in 4H-SiC homo-epitaxial films on large diameter wafers. Close investigation of the dependence of growth rate and carrier concentration on the radial distance from the center of the 150mm wafer revealed that the actual C/Si ratio just above the wafer: surface C/Si ratio, is quite different from the introduced C/Si ratio by using high speed wafer rotation vertical CVD. Defects observed in the epitaxial films are identical to those expected from the surface C/Si ratio, which suggests that the surface C/Si ratio could be a useful indicator for precise control of defect formation as well as for uniform growth on large diameter wafers.

1. Introduction

4H-SiC epitaxial film has been intensively studied, because of increasing attention as key components in a variety of power electronic systems. Defects in the epitaxial films are still the main issue for device fabrication, because the defects originated from the SiC substrates have harmful effects on the reliability of SiC devices. For high-yield and low-cost mass-production of SiC devices, the SiC films on large diameter wafers with highly uniform thickness and carrier concentration as well as with high crystalline quality are required.

Defect formation in the epitaxial film depends on the C/Si ratio [1]. However, to secure the uniform supply of C and Si on a large diameter wafer is essentially difficult. Since the incorporate number of C and Si atoms are the same during the epitaxial growth, the gas-phase concentration of both elements changes along the gas-flow direction. By using single-wafer high speed wafer rotation vertical CVD tool, gas-phase C and Si concentration can be precisely controlled to the radial direction while maintaining the uniformity to the circumferential direction. In this paper, control of the formation of defects by using "surface C/Si ratio" is described. Detailed investigation of growth with various C/Si ratio revealed that C/Si ratio just above the wafer affects the growth characteristics. Two typical results will be shown as examples with the growth under different surface C/Si ratio conditions.

2. Experimental

The configuration of the CVD chamber is shown in Fig. 1. It consists of an upper gas inlet, a hot-wall, a rotation holder, and side/bottom resistive heaters. Process gases are injected into the chamber through injection nozzles. Temperature of the SiC wafer is monitored by pyrometers, and is controlled to the process temperature by feedback system.

Table I summarizes growth conditions used in this study. All of the films were grown on 150 mm diameter 4H-SiC wafers (Si face) at 1625 ºC, rotation speed of 600 rpm and pressure of 26.7 kPa. SiH_4, C_3H_8, H_2, N_2 and HCl were used as the process gases. C/Si ratio was varied by C_3H_8 gas flow rate.

Film thickness and carrier concentration of the films were evaluated by FT-IR and mercury probe C-V measurements with 5.0 mm edge exclusion. Because the film thickness and carrier concentration show concentric distribution, these measurements were performed along the radial direction. Defects of the films grown on wafers sliced from a single lot were evaluated by confocal differential interference contrast (CIDC) microscope and PL imaging with 3.0 mm edge exclusion.

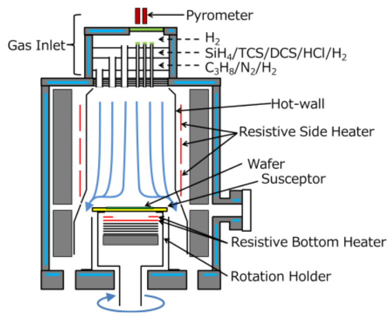

Fig. 1 Schematic illustration of the high speed wafer rotation CVD tool used in this study.

Table I Growth conditions of the SiC films in this study.

Growth parameters	Set values
Temperature [ºC]	1625
Pressure [kPa]	26.7
Rotation speed [rpm]	600
Si/H_2 ratio	2.36×10^{-3}
C/Si ratio	1.2 to 1.95
Cl/Si ratio	10

3. Results and Discussion

Figure 2 (a) shows growth rate of the SiC films measured at different radius on the wafer, depending on C/Si ratio introduced into the chamber. It is clear that the growth rate of the films proportionally increases and turns to saturate with the increase of the introduced C/Si ratio, which is similar to that previously reported [2]. As shown in Fig.2 (a) by the color allows, transition from proportional to saturated region at the wafer edge (R=70mm) occurs at lower introduced C/Si ratio than the center of the wafer (R=0mm). This result indicates the actual C/Si ratio just above the wafer: surface C/Si ratio, is much lower than the introduced C/Si ratio. Moreover, it seems that the surface C/Si ratio increases from inside to outside of the wafer.

Figure 2 (b) shows carrier concentration per unit flow rate of N_2 gas of the SiC films measured at different radius on the wafer, depending on introduced C/Si ratio. The carrier concentration decreases from rapidly to loosely with the increase of the introduced C/Si ratio. It is also shown that decreasing rate of carrier concentration with the increase of introduced C/Si ratio becomes larger, when the distance from inside to outside of the wafer is increased. This phenomenon can be explained by surface C/Si ratio increases from inside to outside of the wafer.

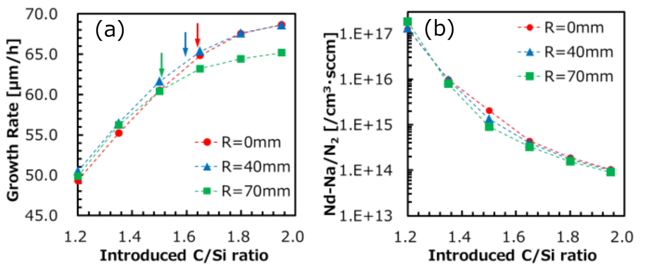

Fig. 2 Growth rate (a) and carrier concentration per unit flow rate of N_2 gas (b) of the SiC films measured at different radius (R=0, 40 and 70 mm) on the wafer, depending on introduced C/Si ratio. In Fig. 2 (a), the color arrows indicate transition point from proportional to saturated region for each distance on the wafer, which were determined from an intersection of the tangential lines of the proportional and the saturation.

C/Si ratio affects not only the growth and carrier concentration but also defect formation. The results shown in Fig. 2 (a) and (b) suggest that defects in the epitaxial layer might depend on the surface C/Si ratio. Figure 3 shows defect maps of SiC films grown at introduced C/Si ratio of 1.35 and 1.80. The thickness and carrier concentration uniformity of both films were less than 1.3% and less than 2.5% (σ/mean), respectively. The former condition corresponds to surface C/Si ratio of less than the transition point in the whole area of the 150 mm diameter wafers and the latter is higher. Defects of these films were categorized into carrots, triangles, down-falls and BPDs. As compared with Fig. 3 (a) and (b), defect density of the film grown with introduced C/Si ratio of 1.8 is much lower than that of 1.35. For both samples, although the defect density at the outside of the wafer is slightly higher than that at the inside of the wafer, it is considered to be a defect distribution due to unevenness of the crystalline quality on the wafer, because of non-uniform defect distribution in the circumferential direction. All of the categorized defects of the film grown at introduced C/Si ratio of 1.8 are reduced compared with that of 1.35, as shown in Fig. 3 (c). In particular, the BPD was not

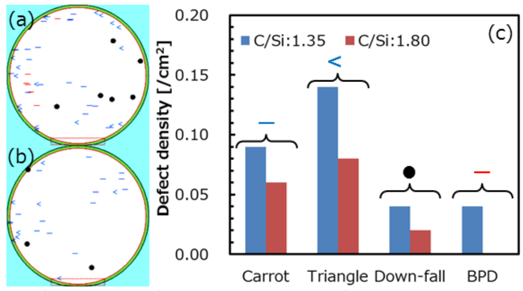

Fig. 3 Defect maps of 10μm thick. SiC films grown at introduced C/Si ratios of 1.35 (a) and of 1.8 (b), and defect density (c) categorized into carrots(-), triangles(<), down-falls(●) and BPDs(-).

obviously observed in the film grown at introduced C/Si ratio of 1.8, it is considered that a combination of high growth rate [3] and high surface C/Si ratio [4] realizes higher conversion rate of BPDs to TEDs.

Figure 4 shows CIDC images of the defect formed on the films grown at different introduced C/Si ratios shown in Fig. 3. Because the similarity of the appearing coordinates of both defects was recognized on the wafers sliced from a single lot, they are considered to be the defects caused by threading dislocations such as TEDs and/or TSDs. The density of these defects appeared on the films grown at introduced C/Si ratios of 1.35 and of 1.80 are 0.32 and 116 cm^{-2}, respectively, which are greatly different. Clearly, the defect appeared at Fig. 4 (b) is a growth pit, which might be caused by threading dislocation. The defect appeared at Fig. 4 (a) thought to be a line shaped growth pit (or a line shaped depression). Different defect shapes thought to be explained by difference of the surface migration of the Si adatoms. Similar phenomena were observed in micropipe dissociation [5].

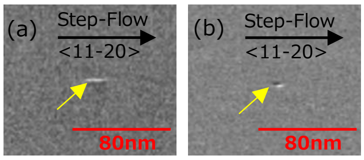

Fig. 4 CIDC images of defect formed on the SiC films grown with introduced C/Si ratios of 1.35 (a) and 1.80 (b), which appeared at almost the same coordinates on two single lot wafers.

4. Conclusions

Surface C/Si ratio was demonstrated as a useful indicator for the control of defect formation in 4H-SiC homo-epitaxial films on large diameter wafers. Formation of defects could be controlled according to the surface C/Si ratio, while achieving the in-wafer uniformity of growth rate and carrier concentration. The surface C/Si ratio could be a useful indicator for optimizing the epitaxial growth condition especially for large diameter wafers.

References

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