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Warpage reduction of thick 4H-SiC epitaxial layers on the substrates

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Abstract

In this study, we grew thick 4H-SiC epitaxial layers on Si-face substrates and attempted to reduce the warpage. The substrates were coved by grinding the C-face before the epitaxial growth in order to cancel out the increase in convex warpage due to the thick epitaxial growth. Consequently, the warpage of the thick epitaxial layer on the substrate was decreased.

1. Introduction

It is expected that 4H-SiC ultra-high-voltage devices that can control voltages above 10 kV to be realized and used for electrical conversion at electric power substations to improve the efficiency. To realize the ultra-high-voltage devices, thick 4H-SiC epitaxial layers over 100 µm are required. However, it is difficult for the thick epitaxial layers on the substrates to be transported by automated systems owing to the large warpage because the warpage increases with the thickness increase of the epitaxial layers [1]. The warpage of the thick epitaxial layers on the substrates must be reduced for the realization of the ultra-high-voltage devices. Here, we grew 4H-SiC n-type epitaxial layers with low carrier concentrations on commercially available n-type substrates with high carrier concentrations. It is reported that the warpage in such cases are convex because the lattice constants of the epitaxial layers are longer than those of the substrates [1]. Therefore, the warpage of the thick epitaxial layers on the substrates would be large convex.

We attempted to reduce the large convex warpage of the thick epitaxial layers on the substrates. It is known that when one side of the substrate is ground, the substrate bends, and the ground side becomes convex because of the residual stress due to the Twyman effect [2]. We consider that the Twyman effect can be utilized for reducing the warpage of the thick epitaxial layers on the substrates. Namely, the substrates are coved by grinding the back side before the epitaxial growth to cancel out the increase in the convex warpage due to the epitaxial growth. In this study, we grew thick 4H-SiC epitaxial layers on the Si-face substrates whose C-faces were ground and investigated the effects for the warpage reduction.

2. Experimental procedures

Epitaxial growth was performed on 3-inch 4H-SiC Si-face substrates with 4° off-angle in a close-spaced vertically blown chemical vapor deposition system, where the substrates were oriented perpendicular to the gas flow for a high growth rate [3]. H_2 was used as the carrier gas, SiH_4 and C_3H_8 were used as the precursors, and N_2 was used as the doping gas. The growth rate was approximately 40 µm/h. In-situ H_2 etching and the epitaxial growth were carried out at 1590 °C and 2.7 kPa. The C/Si ratio was 1.2. The carrier concentrations obtained by capacitance-voltage measurements were approximately 5×10^{14} cm^{-3}.

The warpage was measured using FlatMaster from Corning Tropel. We employed the “SORI” value in the warpage evaluation. Herein, the convex and concave warpages are represented as a positive value (+) and a negative value (-), respectively.

3. Results and discussion

First, we investigated the relationship between the amount of warpage change and the thickness of the epitaxial layers, as shown in Fig. 1. We confirmed that the warpage is convex and increases with the thickness increase of the epitaxial layers. Fig. 1 shows that the amount of convex warpage change is approximately 26 µm (+26 µm) when the thickness is 200 µm in particular.

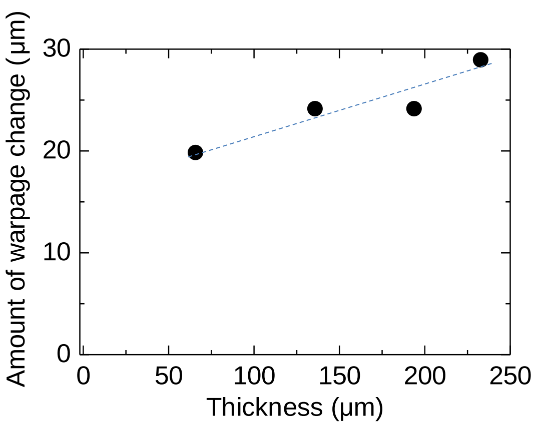

Fig. 1 Relationship between amount of warpage change and thickness of epitaxial layers.

Next, we investigated the warpage of the substrates when the C-face was ground in various conditions. In addition, the warpage of these substrates after H_2 annealing was investigated because in-situ H_2 etching, i.e., H_2 annealing, is proceeded before the epitaxial growth. It is predicted that the H_2 annealing affect the residual stress layer and the warpage would be changed. The relationship between the warpage of the substrates and the roughness of the C-face is shown in Fig. 2. The warpage before annealing and after H_2 annealing are indicated by the black points and red circles, respectively. It indicates that the substrates are coved by grinding the C-face as expected, and the concave warpage increases with the roughness increase on the C-face. It is thought that the residual stress by grinding increased with the roughness increase on the C-face because it has been reported that the depth of the residual stress layer by grinding increases with the increase in surface roughness [4]. Moreover, Fig. 2 shows that the concave warpage of these substrates is decreased by H_2 annealing. It is thought that the residual stress layer by grinding was etched by H_2 annealing or the residual stress was reduced owing to the crystallinity improvement at a high temperature. To investigate which phenomenon had happened, the substrate with the C-face roughness of 60 nm was annealed in an Ar atmosphere. The warpage of the substrate after Ar annealing is indicated by the blue cross marks in Fig. 2. We found that the warpage of the substrates after H_2 and Ar annealing are the same. This indicates that the concave warpage reduction by H_2 annealing occurred because the residual stress was reduced owing to the crystallinity improvement. Thus, the concave warpage was decreased by H_2 annealing but the concave warpage after H_2 annealing was still enough to reduce the warpage of the thick epitaxial layers on the substrates. Fig. 2 shows that the concave warpage of the substrate with the C-face roughness of 60 nm after H_2 annealing is approximately 27 μm (-27 μm).

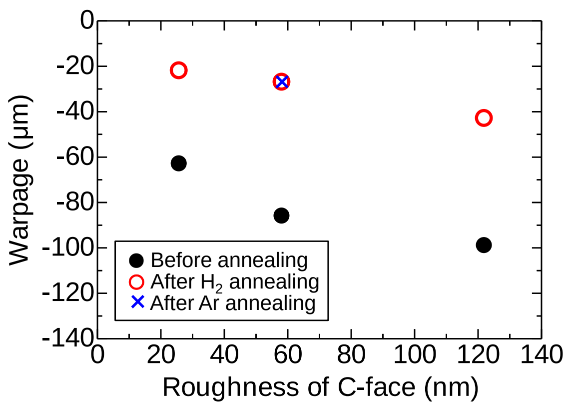

Fig. 2 Relationship between the warpage of substrates and roughness of C-face.

Finally, we used a substrate with ground C-face for a thick epitaxial growth. To reduce the epitaxial layer warpage on the substrate, we grew the epitaxial layer with a thickness of 200 μm on the substrate with a C-face roughness of 60 nm. In this case, the warpage is expected to be concave with a value of 1 μm (-1 μm). The result of the epitaxial layer warpage on the substrate measured using FlatMaster is shown in Fig. 3. Here, the warpage was measured on the C-face because measurements on the Si-face are influenced by the epitaxial thickness distribution. Therefore, Fig. 3 indicates that the warpage is convex with a value of 5 μm (+5 μm). We succeeded in reducing the thick epitaxial layer on the substrate although the warpage value (+5 μm) was slightly larger than the expected value (-1 μm). We conclude that the warpage of thick epitaxial layers on the substrates can be reduced by controlling the roughness of the ground back side in accordance with the estimated amount of warpage change from the objective thickness of epitaxial layers. Moreover, we confirmed that defect density increase of the epitaxial layer did not occur.

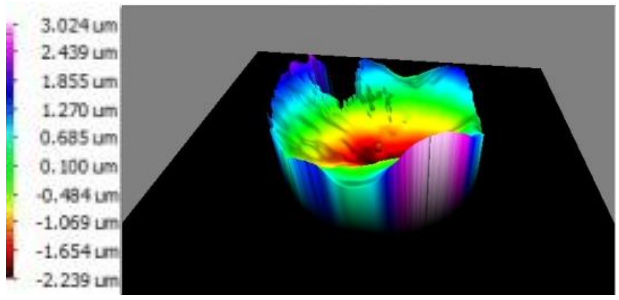

Fig. 3 Warpage, which was measured on the C-face, of the thick epitaxial layer on the substrate.

4. Conclusion

We grew thick 4H-SiC epitaxial layers on Si-face substrates and attempted to reduce the warpage. We found that the increase in the convex warpage due to the epitaxial growth can be cancelled out by grinding the C-face and coving the substrates before the epitaxial growth. We grew an epitaxial layer of thickness 200 μm on a substrate with a C-face roughness of 60 nm. Consequently, we succeeded in reducing the warpage to 5 μm. We conclude that the warpage of thick epitaxial layers on the substrates can be reduced by controlling the roughness of the ground back side in accordance with the estimated amount of warpage change from the objective thickness of epitaxial layers.

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