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Study of In-Grown Micropipes in 200 mm 4H-SiC (0001) Epitaxial Substrate

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Abstract: This paper details the defect inspection and characterization of the 200 mm 4H-SiC (0001) n-type substrate pre- and post-epitaxy. The findings in this paper focus on the characterization of the micropipes (MPs) present in the 200 mm SiC substrate. Following epitaxy, the observations include how the micropipes were propagated from the substrate to the epilayer. This study explores the closing of micropipes during epitaxial growth. As a part of our efforts to better understand the crystal structure and elemental composition of the micropipes in the epilayer, we have conducted SAED and EDX experiments. To the best of our knowledge, it is the first report to demonstrate the region near the micropipe sidewall surface, is remarkably Si-rich (~ 9:1) than in the region towards the bulk (~1:1) after SiC epitaxial growth.

Introduction

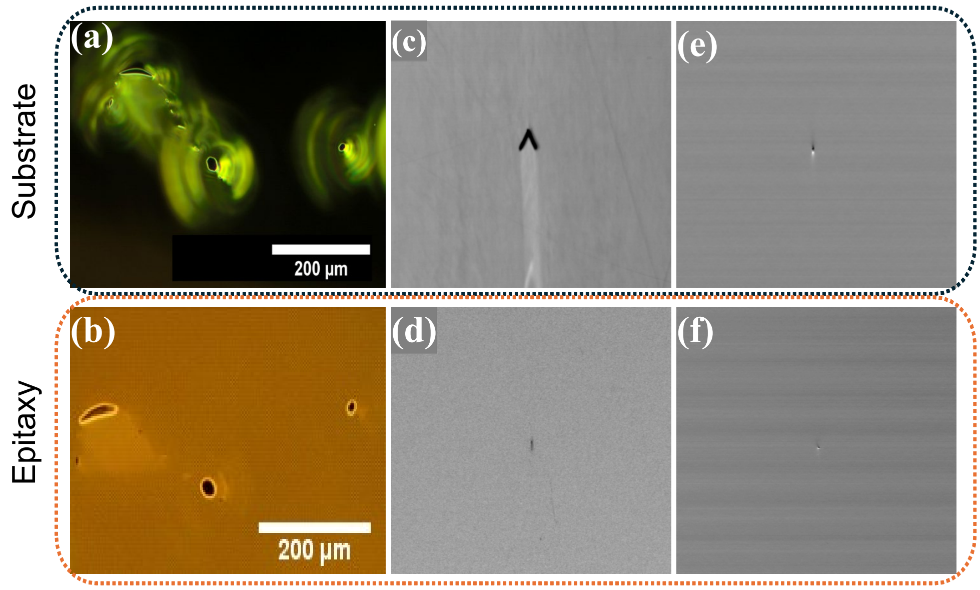
Over the years, substantial research has been carried out on SiC defects and the production of 4H-SiC wafers [1, 2]. Micropipes (MP) are well-known defects in the 4H-SiC substrates and have proven particularly troublesome. There has been some recent discussion that micropipe density has been reduced to a value lower than 1 cm^{-2} on 150 mm SiC substrates [3], but this may not be true for 200 mm wafers. High-quality 200 mm 4H-SiC wafers are still scarce. The quality of 200 mm wafers is questionable, and it is crucial to investigate these defects to achieve higher yields. According to Frank's theory [4], micropipes are hollow-core tubes that extend along the c-axis. Additionally, research on filling micropipes during homoepitaxy on SiC wafers remains unexplored. The performance of high-power devices is adversely affected by micropipes, making this an important area of study [5, 6]. The objective of this research is to investigate the process of filling and closing micropipes during epitaxial growth.

Results and Discussion

The epilayer has a thickness of approximately 10 µm and is grown on a 200 mm 4° off-axis 4H-SiC (0001) wafer. Its dopant concentration is around 10^{16} cm^{-3}, which is two orders of magnitude lower than that of the substrate (approximately 10^{18} cm^{-3}). The surface of the epilayer was examined using atomic force microscopy (AFM) and a root-mean-square (RMS) roughness of (0.19 ± 0.08) nm was obtained at a scan size of 1×1 μm^2. The average width of the terraces was determined to be (8.3 ± 0.6) nm, with a corresponding step height of (5.80 ± 0.04) Å. This indicates a dominant step height of two SiC bilayers, which is consistent with previous research [7].

The KLA Candela 8520 tool was used to examine both the substrate and epilayer. This tool is equipped with an integrated photoluminescence (PL) and surface inspection system, making it ideal for characterizing defects on SiC substrates and epilayers. Since the defects on the epilayers often show visible differences in height, we consider the topographic response as the main signal. We also use the scattered light response as a secondary signal to help identify the micropipe defects. For detailed micropipe defect inspection, we used high-resolution transmission electron microscopy (TEM), selected area electron diffraction (SAED), and energy dispersive X-ray (EDX) to understand the crystallographic information and elemental composition.

Fig. 1(a, b) depicts Nomarski microscope images of a micropipe on the substrate and after epitaxy growth. A micropipe is a screw dislocation with a large Burgers vector that traverses the SiC crystal in a direction parallel or close to the (0001) axis. It manifests as a void on the surface [8]. In the dark field mode, MPs appear as dark spots and scatter light around them, illustrating the high strain fields associated with MPs, as shown in Fig. 1(a). Consequently, a micropipe appears as a bright elongated streak in the scattered light image, extending along the direction of the incident beam. Fig. 1(c, e) shows the micropipe image on the substrate, and Fig. 1(d, e) shows the same location on the epilayer using Candela 8520 for two-channel specular oblique and raw radial topography oblique channels, respectively.



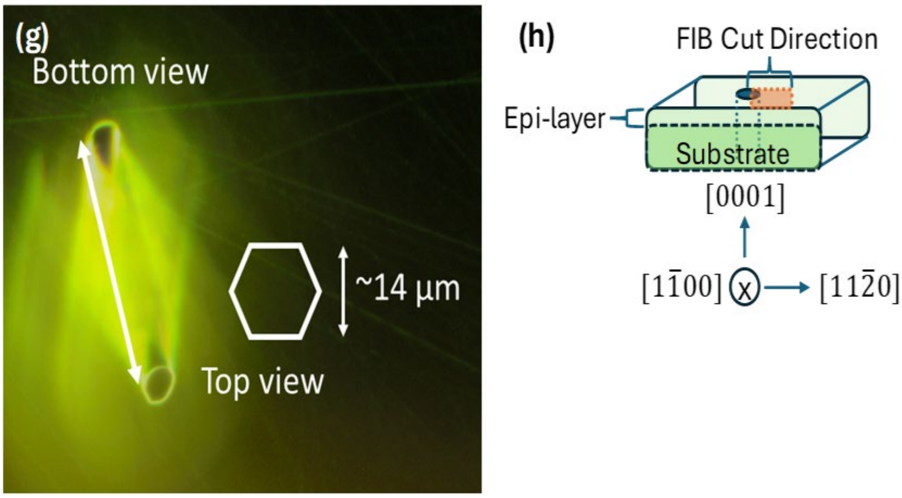


Fig.1. Examined MPs (a-b) Candela two-channel specular oblique channel, (c-d) raw radial topography oblique channel, (e-f) OM dark-field, (g) MP from the top and bottom from OM dark-field. (h) Schematic of the FIB cut direction for TEM measurement.

The micropipe on the substrate initially had a diameter of 14 µm, as seen in Fig. 1(g). However, after 10 µm of epitaxial layer growth, the diameter decreased to less than 10 µm. This indicates that material growth is occurring on the sidewall of the micropipe. To examine the material on the sidewall and its crystal structure in more detail, we conducted cross-section TEM experiments. We used a focused ion beam (FIB) to cut the sample at the edge of the micropipe along $(11\bar{2}0)$ direction for structure and composition analysis. We employed SAED to understand the crystal nature of the grown sidewall material. To better understand the diffraction pattern, it was simulated using CrystalMaker software.

Fig. 2(a) shows the TEM image of the bulk epilayer, and the simulated electron diffraction results are shown in Fig. 2(b). It is noticeable that a distinct clear diffraction pattern from several crystal planes confirms the high-quality crystallinity of the epitaxial film. The material composition, verified by EDX as seen in Fig. 2(c), shows the stoichiometry of SiC material. Fig. 3(a) shows the TEM image close to the micropipe location. Fig. 3(b,c) shows the SAED patterns extracted near the micropipe sidewall. The simulated diffraction pattern shows that additional crystal planes appear, suggesting that the sidewall material is not 4H-SiC or that the stoichiometry of SiC changes. To examine this, EDX analysis was conducted, and the results shown in Fig. 3(d) reveal that the surface region close to the micropipe location is remarkably Si-rich (~ 9:1) than in the region towards the bulk (~1:1). Our study is the first to show that Si-rich sidewalls of micropipes grow during SiC growth. Further study is needed to understand the phenomena of the filing of MPs.

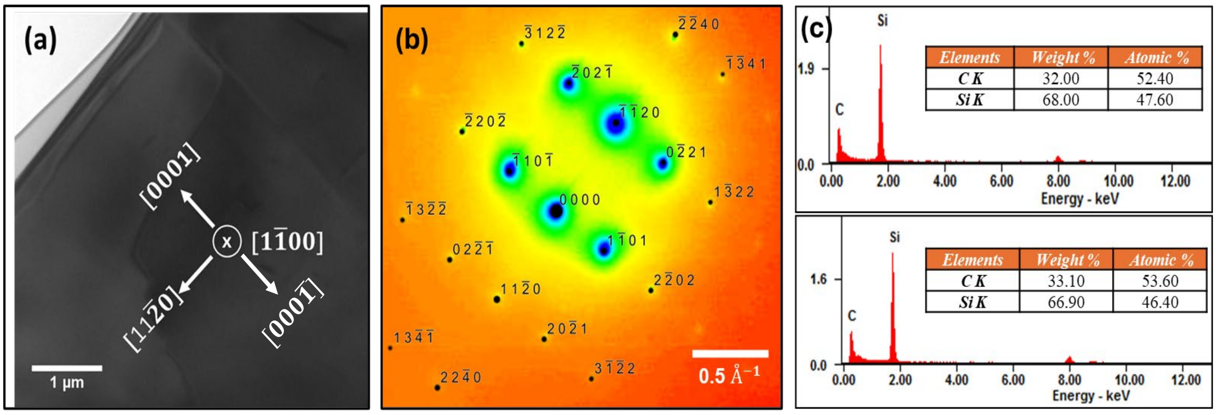


Fig. 2. (a) TEM image of the bulk epilayer, (b) SAED patterns, (c) EDX measurement at two different locations in bulk.

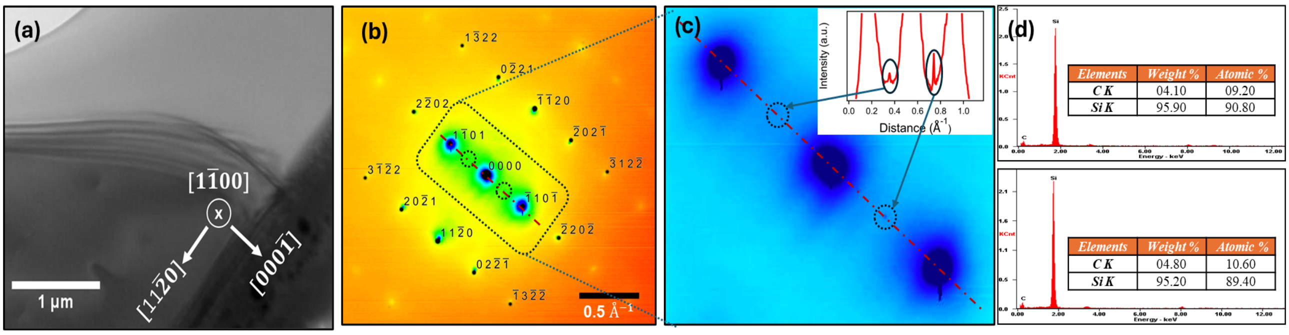


Fig. 3. (a) TEM image of the side wall of MP, (b) SAED patterns, (c) zoom of the Fig. b inset shows the diffraction pattern along the line. (d) EDX measurement at two different locations on the side wall of the MP.

Conclusion

This study investigated the closing of micropipes during epitaxial growth. We observed that the stoichiometry of SiC close to the MP sidewall location is remarkably Si-rich.

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