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BPD-Free Dicing of Epitaxial SiC Wafers Using Water Jet Guided Laser

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Abstract. Silicon carbide (SiC) wafers are essential for next-generation power devices; however, conventional dicing methods often induce cracks and Basal Plane Dislocations (BPDs), reducing device reliability. This study demonstrates BPD-free dicing of epitaxial SiC wafers using Water jet Guided Laser (WGL) processing. Full-thickness cutting was performed on 350 μm-thick wafers with a 10 μm-thick epitaxial layer using a YAG laser (532 nm wavelength, 200 ns pulse width, 10 kHz repetition rate, 30–80 W output) on an LB300 system. BPD evaluation was carried out by X-ray topography (XRT) with the -1-128 reflection before and after cutting. The results showed no generation or propagation of new BPDs, and pre-existing BPDs did not glide, confirming that WGL processing enables BPD-free machining. These results are attributed to the ablation-based nature of WGL with water assistance, which avoids mechanical stress on epitaxial SiC wafers.

Introduction

Silicon carbide (SiC) wafers are increasingly used in next-generation power devices due to their superior power handling and efficiency characteristics. In SiC power devices, the epitaxial layer is particularly important because it is closely related to the active region where device operation occurs. Therefore, defects introduced into or propagated near the epitaxial layer during dicing may directly affect device performance and long-term reliability. For this reason, it is necessary to evaluate not only the macroscopic cutting quality, such as kerf width and chipping, but also the crystallographic quality of epitaxial SiC wafers after dicing [1]. Various dicing and separation methods, including ultrasonic-assisted wafer sawing and laser-based separation techniques, have been investigated for hard and brittle SiC wafers [2-4]. Although these methods are effective for chip separation, process-induced mechanical loading and thermal effects must be carefully considered in SiC device manufacturing. Therefore, achieving defect-free, particularly BPD-free, dicing remains a significant challenge. This study aims to demonstrate a BPD-free dicing technique for epitaxial SiC wafers using Water jet guided laser (WGL) processing. As illustrated in Fig. 1, WGL utilizes a high-pressure, micron-scale water jet as an optical waveguide for a pulsed laser beam, facilitating precise material ablation and simultaneous cooling [5]. The water jet confines and guides the laser beam due to total internal reflection within the jet, allowing the laser to maintain a tight focus over a longer working distance. This guidance effect reduces beam divergence and enables highly accurate, narrow kerf cutting. In addition, the water jet removes debris from the cutting area, preventing redeposition and thermal damage to surrounding material. The combination of optical guidance and cooling allows WGL to perform defect-free machining even on brittle or hard materials. Moreover, by adjusting the water pressure and jet diameter, the energy density of the laser at the workpiece can be precisely controlled, optimizing the ablation efficiency. While previous studies have shown that WGL did not generate BPDs in bulk SiC, its applicability for dicing epitaxial layers has not yet been confirmed. In addition, the damage-free nature of WGL dicing was evaluated by analyzing XRT images of grooved SiC wafers from two directions and by performing EDX analysis on the cleaved surfaces. Although previous studies have evaluated WGL-grooved SiC wafers using XRT and EDX analysis [6–7], the effect of WGL full-thickness cutting on the BPD distribution of epitaxial SiC wafers has not been sufficiently investigated. Since XRT is effective for observing crystallographic defects such as BPDs in SiC wafers [8], the same area was examined before and after cutting in this study. This approach enables evaluation of whether detectable BPDs were newly generated or whether pre-existing BPDs propagated during WGL full-thickness cutting. In this study, WGL-based dicing is applied to epitaxial SiC wafers, and the resulting crystal quality is evaluated by X-ray topography (XRT).

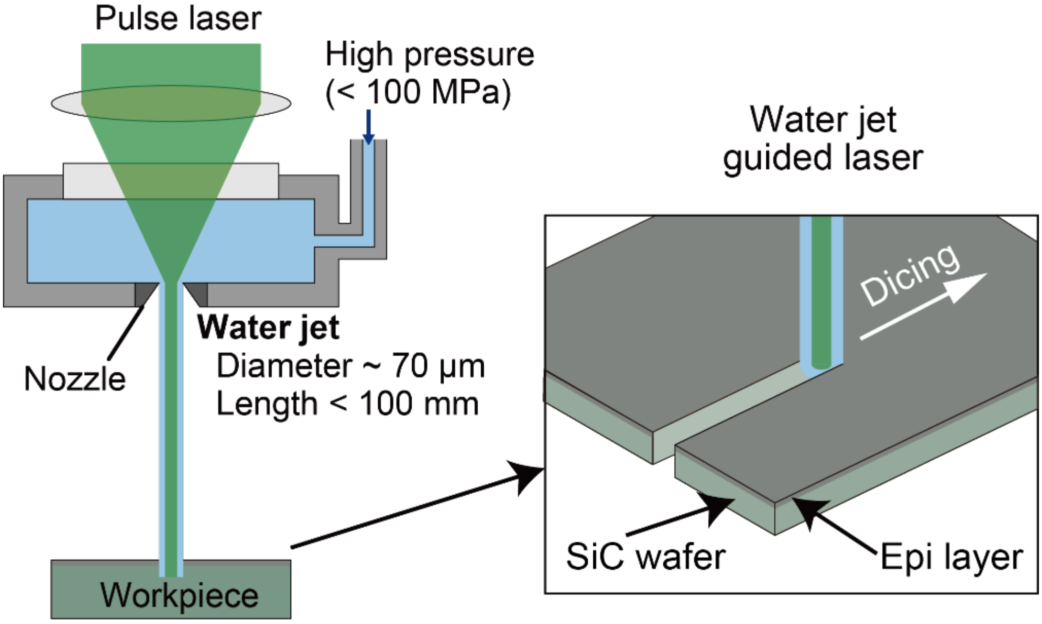

Fig. 1. Schematic illustration of WGL.

Method

A schematic view of WGL dicing is shown in Fig. 1, and the experimental flow for BPD evaluation is shown in Fig. 2. To evaluate whether WGL processing induced detectable new BPDs or caused the propagation of pre-existing BPDs, XRT observations were performed at the same position before and after cutting. In step (a), alignment markings were processed to enable positional correlation between the pre- and post-processing XRT images. In step (b), XRT observation was performed near the alignment markings before WGL cutting. In step (c), the SiC wafer was fully cut by WGL inside the marked region. In step (d), XRT observation was performed again at the same position after WGL dicing. The alignment markings were used as reference features to identify the same observation area before and after WGL cutting. The WGL cutting path was set inside the marked region so that the area surrounding the cut could be included in the XRT observation field. This arrangement allowed the BPD distribution near the full-thickness cutting region to be compared directly before and after processing. The XRT observation area was selected to include both the cutting region and the surrounding wafer area. Therefore, changes in BPD-related line contrasts could be evaluated with respect to the initial defect distribution of the wafer.

The wafer was mounted using dicing tape, and the working distance between the nozzle and the wafer surface was set to 10 mm. Full-thickness cutting was performed on a 350 μm-thick SiC wafer with a 10 μm-thick epitaxial layer using an LB300 system. The main WGL processing conditions are summarized in Table 1. BPD evaluation was conducted before and after WGL cutting at the same position using XRT with the -1-128 reflection. The XRT evaluation conditions are summarized in Table 2.

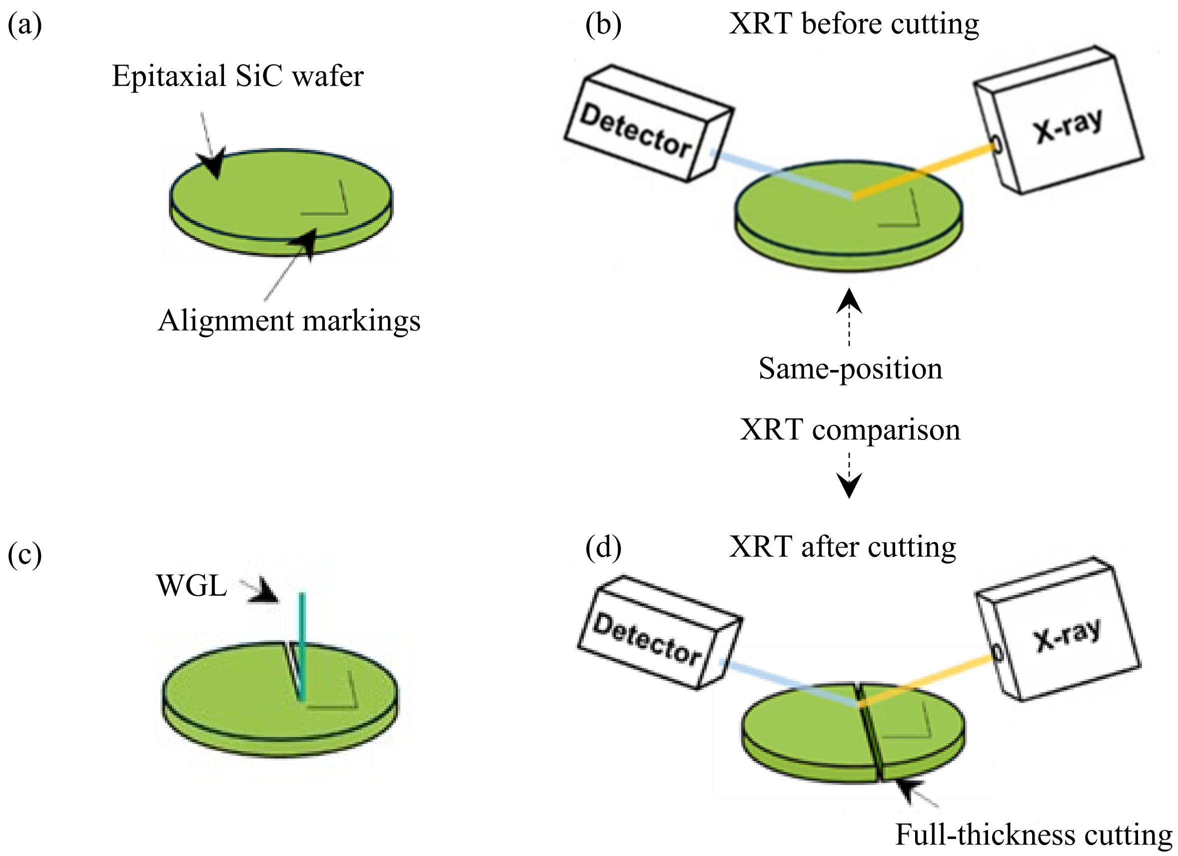

Fig. 2. Process flow for BPD evaluation at the same position using XRT observation.

(a) Alignment markings for position identification.
(b) XRT observation before WGL cutting.
(c) WGL full-thickness cutting inside the marked region.
(d) XRT observation at the same position after WGL cutting. The BPD distributions before and after processing were compared in the XRT observation area.

Table 1. WGL processing conditions used for full-thickness cutting of the epitaxial SiC wafer.

Item	Condition
Workpiece	Epitaxial SiC wafer
Wafer thickness	350 µm
Epitaxial layer thickness	10 µm
Machine	LB300, Makino Milling Machine Co., Ltd.
Laser source	YAG laser
Wavelength	532 nm
Pulse width	Approximately 200 ns
Repetition rate	10 kHz
Output power	30–80 W

Table 2. XRT evaluation conditions used for comparing BPD distributions before and after WGL cutting.

Item	Condition
Evaluation method	X-ray topography
XRT system	XRTmicron, Rigaku Holdings Corporation
Reflection	-1-128
Exposure area	8.0 mm × 6.0 mm
Pixel size	2.3 μm

Results and Discussion

As shown in Fig. 3, XRT images were acquired before and after WGL full-thickness cutting to evaluate changes in the BPD distribution. The overview XRT images in Fig. 3(a) and (b) show the same observation area before and after processing. The overall distribution of line contrasts attributed to pre-existing BPDs was maintained after processing, and no significant change in the defect contrast was observed around the cutting region. This result indicates that no detectable generation or propagation of BPDs occurred within the XRT observation area. This stability of the BPD distribution was confirmed not only in a single observation area but also in multiple regions of the wafer. In addition, similar tendencies were observed for cutting directions rotated by 90 degrees, indicating that the absence of detectable BPD generation was reproducible under the present experimental conditions. These observations suggest that WGL processing can maintain the initial BPD distribution of epitaxial SiC wafers during full-thickness cutting. Specifically, Fig. 3(c)–(h) shows magnified XRT images of selected areas before and after processing, where no emergence or growth of BPDs was observed. The contrast in images (c)–(h) was adjusted to improve BPD visibility. In particular, images (c) and (d) confirm that no new BPDs were generated in areas initially free of BPDs, while images (e)–(h) demonstrate that even pre-existing BPDs (δ, ε) did not glide during processing. The absence of detectable BPD generation and propagation is considered to be related to the non-contact and water-assisted nature of WGL processing. Unlike blade dicing, WGL removes material mainly by laser ablation without direct mechanical contact with the wafer. In addition, the water jet assists cooling during processing. These characteristics can reduce process-induced mechanical loading and suppress excessive thermal influence around the cutting region, which is consistent with the stable BPD distribution observed by XRT.

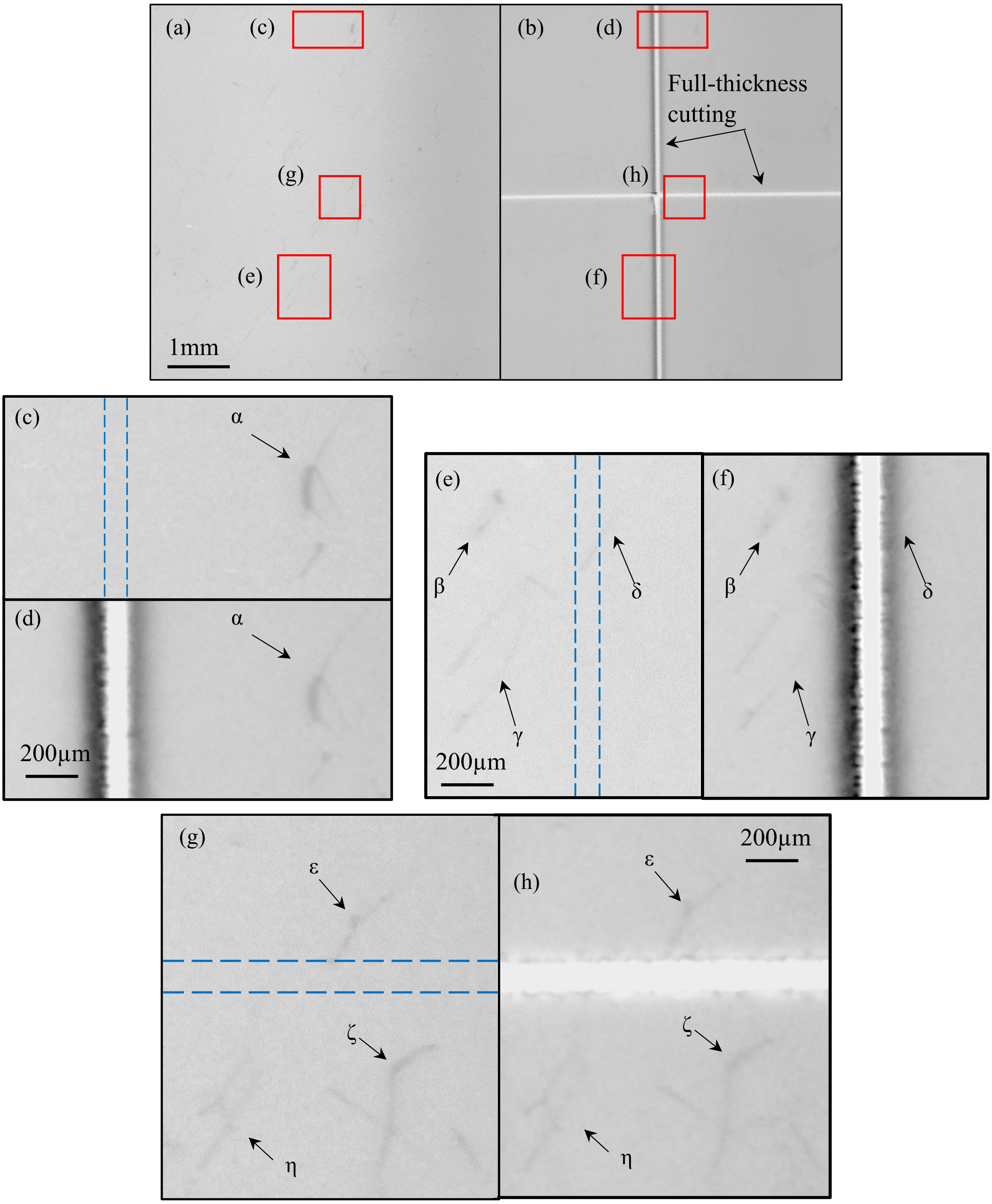

Fig. 3. XRT images of full-thickness cutting.

(a), (b) XRT images before and after processing.
(c), (e), (g) magnified XRT images of selected areas before processing.
(d), (f), (h) magnified XRT images of selected areas after processing. α-η indicate pre-existing BPDs. (Contrast was adjusted in (c)-(h) to enhance the visibility of BPDs.).

Conclusion

In this study, Water jet Guided Laser (WGL) processing was applied to full-thickness cutting of epitaxial SiC wafers. XRT evaluation before and after processing confirmed that no new Basal Plane Dislocations (BPDs) were generated and that pre-existing BPDs did not propagate or glide. These results confirm that WGL processing enables BPD-free machining by an ablation-based technique with water assistance that does not impart mechanical stress to epitaxial SiC wafers. Future studies will be directed toward optimizing the processing parameters and validating the technique under mass-production conditions for practical application in SiC power device fabrication.

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