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Proposal of Damage-Free SiC Wafer Dicing Using Water Jet Guided Laser

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Abstract. A damage-free SiC wafer dicing method has been strongly required for practical applications of power devices. In this research, we propose water jet guided laser processing as a novel dicing method. Water jet guided laser processing, which uses a high-pressure fine water jet as waveguide, could generate no cracks or dislocations in crystal. In this paper, water jet guided laser grooving quality was evaluated to demonstrate there should be no chippings and basal plane dislocations. Scanning electron microscopic and X-ray topography observations were conducted. The results indicated the superiority of water jet guided laser dicing to a conventional dicing method.

Introduction

SiC is one of the most important semiconductor materials applied to power device that is used under high power, high frequency, and high efficiency. Efficient SiC wafer dicing methods are essential for practical applications. Conventionally, several dicing methods have been proposed and used, for example, blade dicing, Stealth Dicing, and Laser dicing. Blade dicing is a mechanical stock removal process using diamond blades. Ultrasonic-assisted blade dicing has been proposed for processing hard and brittle materials such as SiC [1]. Stealth Dicing forms a modified layer and cracks inside a wafer by transmissible laser beam, and then the wafer is broken up by tensile stress [2]. This method is completely dry laser dicing and free from debris and contaminants. In Laser dicing, thermal stress is applied to a wafer, and the wafer is broken up by tensile stress caused by rapid cooling [3].

Conventional SiC dicing methods cause cracks or dislocations in crystal such as basal plane dislocations (BPDs) because they apply mechanical or thermal stress to a wafer. These damages may result in stacking faults formations inside the dices (devices) when the devices are operated under forward-bias conditions [4]. In SiC power devices, these faults could affect critically and should be avoided to ensure device performance and reliability.

In this research, we propose a damage-free dicing method using water jet guided laser processing (WGL). This method should not apply any mechanical stress to a processed wafer and cut it only with a laser ablation phenomenon. In this paper, fundamental dicing tests were conducted to characterize the WGL dicing. In addition, comparison with the conventional blade dicing for chipping and BPD formation was carried out to demonstrate its superiority.

Principle of Water Jet Guided Laser Processing

WGL is one of laser machining methods using pulsed laser and a high-pressure water jet [5]. The principle of WGL is shown in Fig. 1. A water jet with a diameter of several tens of micrometers is formed at pressure of several tens of megapascal. Processing laser is coupled with the water jet through an objective lens and an optical window. The laser light propagates through the water jet as a waveguide with total internal reflection. Thus, the light energy reaches the end of the water jet keeping the same diameter, which is a peculiarity of WGL different from the conventional dry laser processing using focused beam. The workpiece is ablated by the light energy, and simultaneously, cooled down by water. As an effect of the water jet, processed debris is ejected, and the workpiece is processed straight along the water jet.

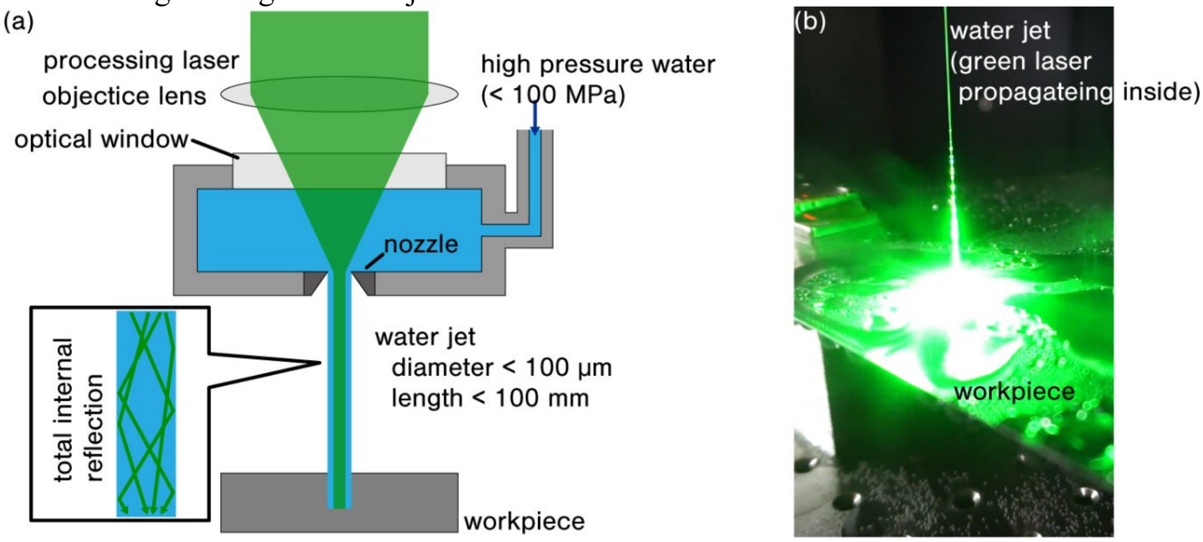

Fig. 1. (a) Principle of water jet guided laser processing and (b) photo image of water jet with green laser propagating inside.

In WGL dicing process, processed material (SiC) is removed only by thermal ablation. There could be almost no generation of cracks or dislocations in crystal such as BPDs since no mechanical stress is applied to the wafer. In addition, there could be little thermal effect on the peripheral part because it is quickly cooled by water. The processed part is not tapered but perpendicular to the wafer surface since the water jet could behave as a straight waveguide. These advantages could make WGL superior as a SiC wafer dicing method.

Experimental

WGL grooving of SiC wafer. Groove profiles were processed on a 4H-SiC wafer with typical WGL condition. A general WGL machine (MCS300, Makino Milling Machine Co., Ltd.) was utilized. A water jet was ejected with water pressure of 20 MPa from a nozzle with a diameter of 80 μm. With assist gas (helium), the water jet could reach to < 100 mm, then distance from the nozzle and wafer was set at 25 mm. Processed laser wavelength was 532 nm to assure the transparency in water and processability for SiC. Pulsed laser condition was as below; pulse width of approximately 200 ns, pulse frequency of 10 kHz and laser power of 80 W. Figure 2(a) shows an example of groove processed wafer surface, which was processed with a scanning speed of 80 mm/s. Approximately 80 μm width, corresponding to the water jet diameter, groove was formed. There were some debris beside the groove. The dicing street width including the debris was approximately 100 μm. Figure 2(b) shows depth dependence on scan times for each scanning speed. The removed depth of SiC wafer was 15–20 μm with one scanning, and the grooving depth became deeper with the scan times. Since the overlapping ratio of each pulse of processing laser could be affected by the scanning speed, the lower scanning speed caused the deeper grooving. It should be noted that the processing efficiency could be enlarged with optimized processing conditions such as laser fluence, laser pulse shape, and/or scanning speed.

To compare with the WGL processed wafer, another specimen was processed by ultrasonic-assisted blade dicing. Groove profiles were formed at scanning speed of 20 mm/s. The width and depth of grooves was 40–60 μm and 70–80 μm, respectively.

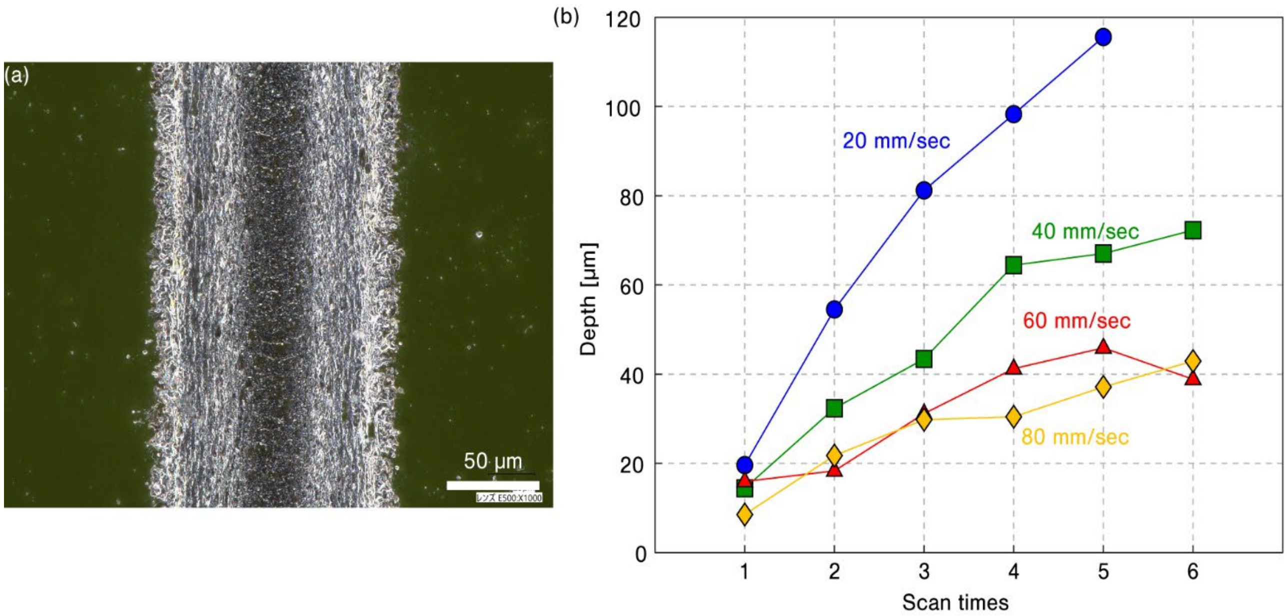

Fig. 2. (a) Optical microscopic image of WGL processed SiC wafer, and (b) groove depth dependence on scan times for each scanning speed.

Evaluation of dicing damages. Processed SiC wafer states were evaluated by scanning electron microscopy (SEM) and X-ray topography (XRT). Edge chipping damage of the wafers was evaluated by SEM images with JSM-6010LA (JEOL Ltd.). In addition, BPD formation in the wafers was evaluated by XRT with XRTmicron (Rigaku Corp.). XRT measurements were performed with 11–28 reflection.

Results and Discussions

SEM images of groove processed wafers are shown in Fig. 3. There was chipping damage on the groove edge in case of blade dicing in Fig. 3(a). This indicates that mechanical impact was applied to the wafer. On the other hand, in case of WGL, there was no chippings or cracks on the groove edge in Fig. 3(b). In addition, there was porous structure in the groove of WGL. This feature could be formed by ablation process, it means, there had been no mechanical stress in the groove, and it is expected that no distortion of a wafer could occur during dicing process. The warp / bow measurement is required to show the wafer distortion during WGL process.

XRT images of WGL and blade dicing processed wafers are shown in Fig. 4. Some background dislocations (BPDs) were seen throughout the specimens as gray line contrasts. There were many arc-shaped BPD contrasts around the blade dicing grooves in Fig. 4(a). This feature could be typical processing damage of blade dicing. On the other hand, there was any significant BPD contrast compared to the background on the WGL processed specimen in Fig. 4(b). For more precise analysis, XRT measurement and BPDs comparison should be carried out with epitaxy layer, which has almost no background BPDs, to check the final defectivity.

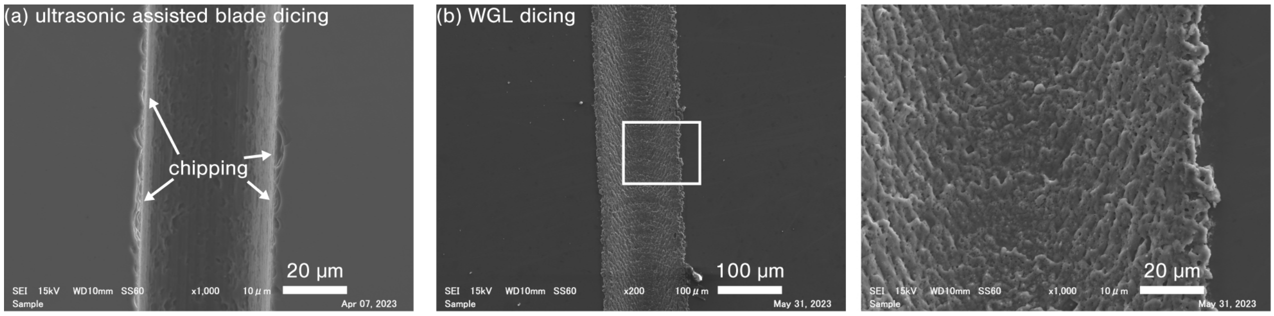

Fig. 3. SEM images of groove processed SiC wafer: (a) ultrasonic assisted blade dicing and (b) WGL dicing (scanning speed 40 mm/s).

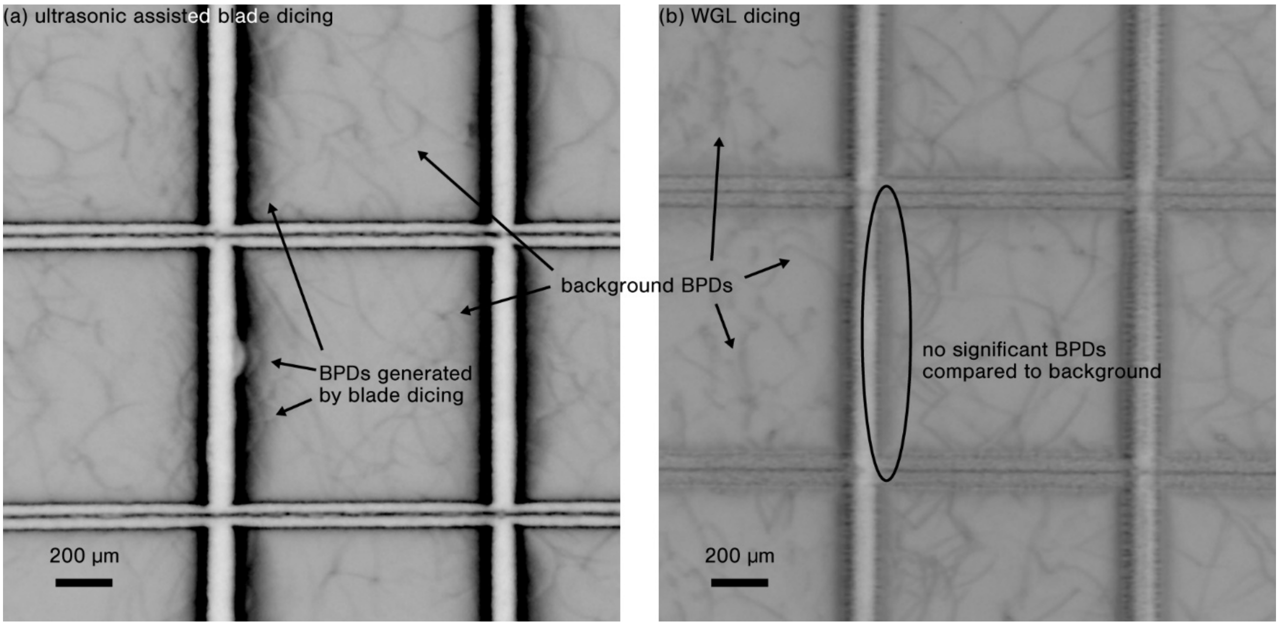

Fig. 4. XRT images of groove processed SiC wafer: (a) ultrasonic assisted blade dicing and (b) WGL dicing.

SEM and XRT results indicated that WGL dicing applied no mechanical stress to the wafer and formed no chippings, cracks, or dislocations. Though it is necessary to examine the processing conditions, it could be said that the superiority of WGL was demonstrated by the fact that no chippings and BPDs were observed around the WGL processed grooves. In addition, the features of no chipping and dislocations beside the dicing groove suggests that WGL could reduce the edge termination area, it means, the production yield of the chip from a wafer could be improved. Since the dicing street width of WGL including debris dominantly depends on the nozzle diameter, the narrower dicing street could be achieved with a finer nozzle.

Conclusions

A novel SiC wafer dicing method using WGL was proposed. WGL has been expected as a damage-free SiC dicing method which causes less chipping and BPD. Experimental results indicated that porous structure was formed on the processed part by laser ablation and that no mechanical stress was applied to the wafer in the WGL process. In addition, comparison with respect to chipping and BPD formation in processed wafers was conducted using SEM and XRT observations between WGL and conventional ultrasonic-assisted blade dicing. While numerous chippings and BPDs were caused by blade dicing, no chippings and BPDs were observed in the WGL processed specimen. These results fundamentally indicated the superiority of WGL to the conventional dicing methods.

For future work, the processing conditions should be optimized in terms of the dicing street width and processing efficiency.

Acknowledgements

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References

[1] Y.H. Wang, J.M. Hsu, M.H. Weng, C.H. Chen, Y.C. Hsieh, in Proceedings of CSS MANTECH Conference (Denver, Colorado, USA, 2014) pp. 271–274.

[2] E. Ohmura, F. Fukuyo, K. Fukumitsu, H. Morita, J. Achievements in Materials and Manufacturing Engineering, vol. 17, pp. 381–384 (2006).

[3] D. Lewke, K.O. Dohnke, H.U. Zühlke, M.C. Barreto, M. Schellenberger, A. Bauer, H. Ryssel, Mater. Sci. Forum, vol. 821–823, pp. 528–532 (2014).

[4] M. Skowronski, S. Ha, J. Apply. Phys. 99, 011101 (2006).

[5] B. Richerzhagen, U.S. Patent No. 5,902,499 (11 May 1999).