

Evaluation of Line-Shape Defect in Epitaxial Wafer

Ling Guo^{a*} and Daisuke Shiomi^b

SHOWA DENKO K.K. Device Solutions Division, 1505 Shimokagemori, Chichibu-shi, Saitama
369-1893, Japan

^aguo.ling.xhjxe@showadenko.com, ^bshiomi.daisuke.xhixv@showadenko.com

*Corresponding author

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Abstract. In this study, we investigated the origin of line-shape defect in 4H-SiC epitaxial wafers. The inspection results revealed that such defects resulted from the substrate entirely and accompanied with dislocation lines during the epitaxial process. Although the defect surface condition with nanometer level of roughness seemed to do little harm to the initial electrical characteristics of power devices, dislocation lines possibly resulted in high leakage current when reverse voltage was applied. To reduce line-shape defects, it is essential to reduce defects and threading dislocations in substrates and to develop a nondestructive method for wafer screening.

Introduction

Nowadays SiC Schottky barrier diodes (SBDs) and MOSFETs for various applications are already commercially available with the rapid development of semiconductor technology. To meet the needs of high device yield, thick SiC epitaxial wafers ($> 30 \mu\text{m}$) with low particle defect density have been developed.

As is commonly known, triangular defects (bunched-step segment) [1] resulting from particles during epitaxial growth, large-pit defects [2] resulting from carbon-inclusion defects in substrate, and pit defects [3] resulting from fabrication process are regarded as killer defects for SBDs and planar-MOSFETs. In addition, the line-shape defect (LSD; stacking fault complex), which is classified as *Diagonal* by confocal microscopy with differential interference contrast (CDIC) (SICA88, LaserTec Corp.), has also attracted the attention of device manufacturers because of its potentially bad influence on reverse electrical characteristics of power devices recently.

By comparing wafers in different states, we found that LSDs resulted from substrate entirely and appear as straight or curved lines on the surface of epitaxial wafers. Because it was not clear whether these defects would affect the initial electrical characteristics of power devices, the origins, structures and possible effects on devices of LSDs were investigated and discussed in this study.

Experimental

Taking advantage of high-quality epitaxial growth technology, approximate 11- μm -thick n-type epitaxial layers with low particle defect density ($< 0.1/\text{cm}^2$) on 4H-SiC substrates were prepared. To investigate the origin of LSDs, CDIC and photoluminescence (PL, $\lambda > 660 \text{ nm}$) observation of wafers were performed before and after epitaxial growth. The surface condition of a defect was inspected by hybrid laser microscopy (OPTELICS, Lasertec Corp.). Emission spectrum measurement (PLIS-100, PHOTON Design Corp.) was conducted to identify the type of stacking fault defects if any. Besides, cross-sectional scanning transmission electron microscopy (STEM) to reveal the structural features of the defects was performed, checking if polytype, dislocation line or foreign matter existed.

Results and Discussion

Fig. 1 shows CDIC and PL images of the same location on the wafer inspected at two different stages: as-substrate and as-epitaxial. It was found that LSDs mainly resulted from scratches, bar-shape stacking faults (BSF), black patterns in PL images (PL-black), and even no obvious surface abnormalities in 4H-SiC substrates. Past research also found that carbon-inclusion defects might result in LSDs with the extremely low conversion rate ($\sim 1.6\%$). In this study, we investigated LSDs resulting from the above four different origins, in samples A, B, C, and D. Although the origins of LSDs were different, stacking faults (SFs) observed in PL images of A, B, and D looked very similar. Therefore, the destructive analysis method is necessary for further distinction.

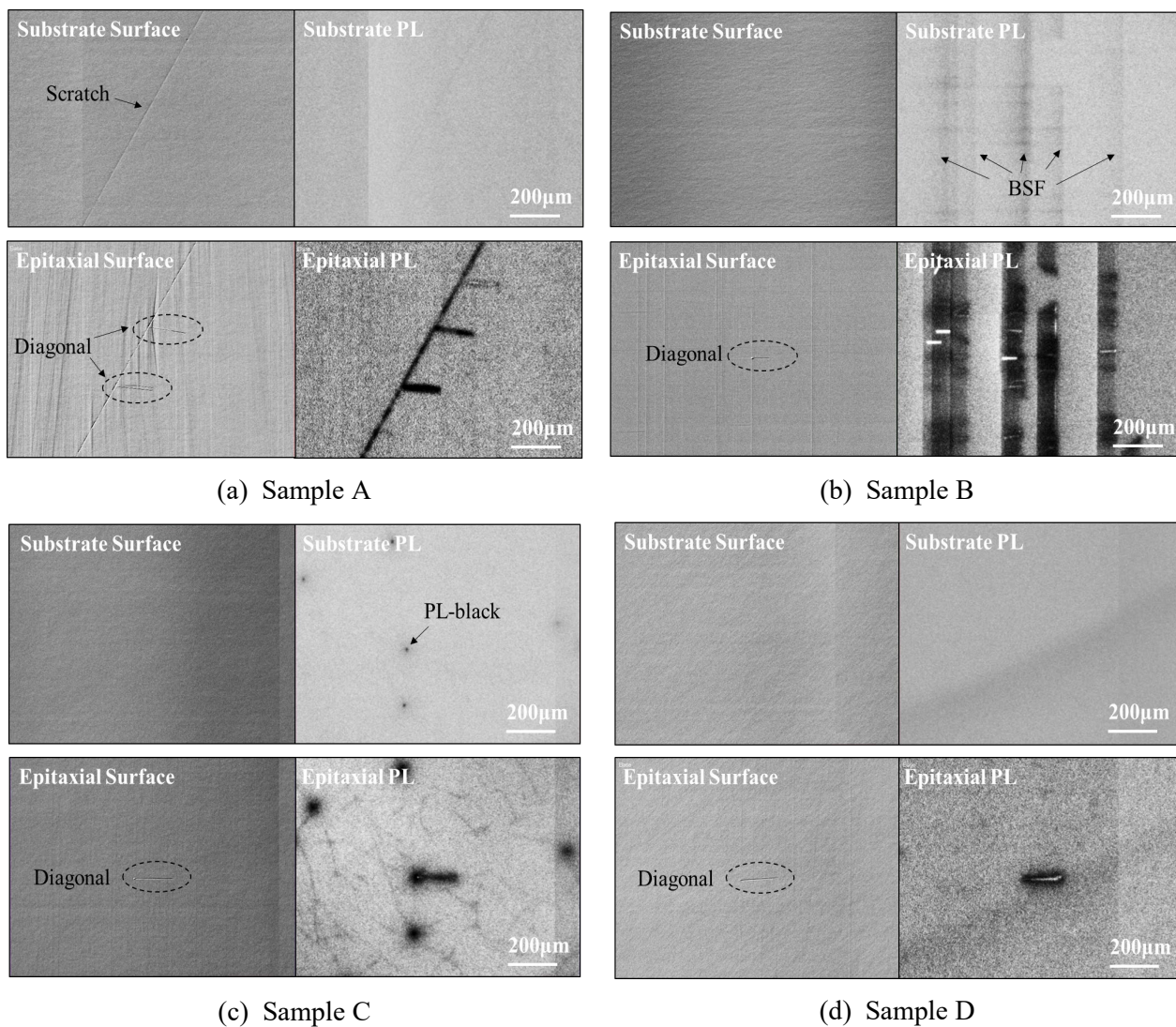


Fig. 1. CDIC and PL images of line-shape defects.

Firstly, the surface condition in Fig. 2 shows that LSDs consist of start point and line shape. The start point turned out to be a pit in sample A and D, a bump in sample B, but no obvious abnormality in sample C. The line shape of LSDs had a valley–peak–valley structure in common, with the height between peak and valley ranging from 10 to 40 nm (Table 1). Therefore, it was assumed that roughness at the nanometer level could do little harm to the leakage current of the initial electrical characteristics of devices.

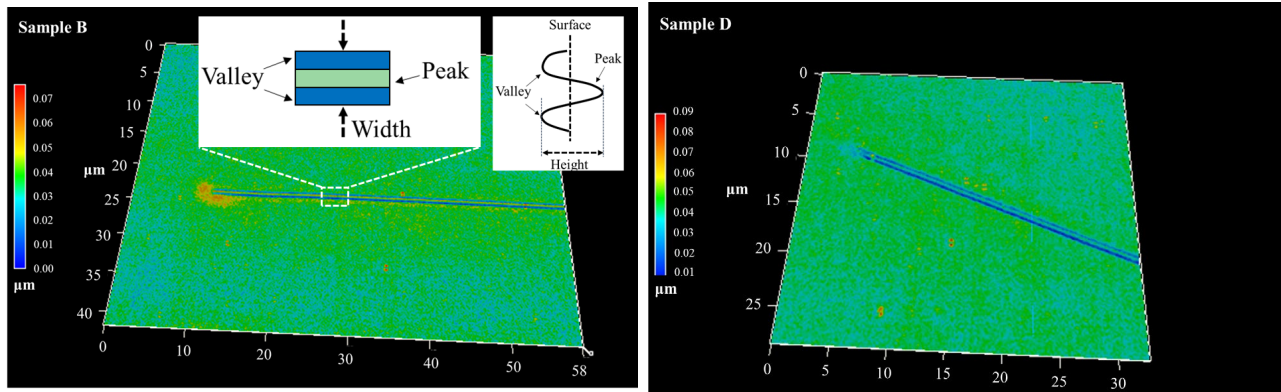


Fig. 2. Surface condition of line-shape defect.

Table 1. Summary of surface condition.

Sample	Origin	Start point	Width [μm]	Height [nm]
A	Scratch	Pit	2.5	10
B	BSF	Bump	1.0	30
C	PL-black	-	0.7	30
D	Unknown	Pit	1.2	40

STEM of the four samples revealed that LSDs were accompanied by SFs and dislocation lines at the substrate–epitaxial interface (Fig. 3). SF types were confirmed by stacking sequence observation, and the result was consistent with the emission spectrum measurement. SF types of samples A, C, and D proved to be Frank-type, and the formation mechanism was almost the same as that of a Carrot defect [4].

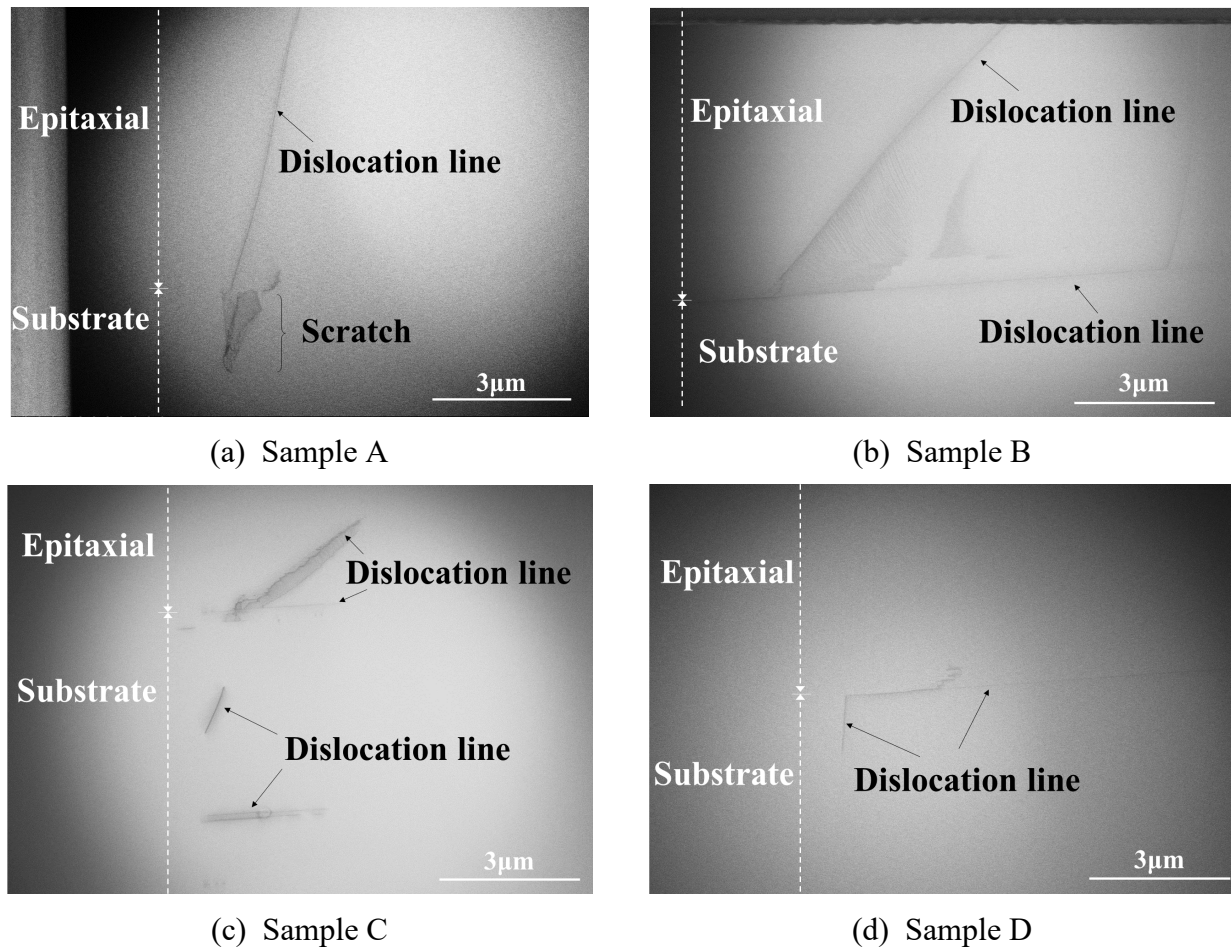


Fig. 3. Cross-sectional STEM image of substrate-epitaxial layer interface in defect.

Table 2. Summary of line-shape defect analysis.

Sample	Origin	SF Type	Peak Wavelength	3C-SiC	Carbon-inclusion	Dislocation Type	
						Substrate	Epitaxial
A	Scratch	Frank	486 nm	None	None	None	TMD
B	BSF	Bar-shape	422 nm	None	None	None	TED
C	PL-black	Frank	486 nm	None	None	TMD	TSD,TMD
D	Unknown	Frank	486 nm	None	None	TSD,TMD	TSD,TMD

Dark-field observation to distinguish the dislocation types revealed threading screw dislocation (TSDs) and threading mixed dislocation (TMDs) in the substrate and epitaxial layer in samples C and D, indicating a possible leak path during reverse voltage measurement [5], but there was only threading edge dislocation (TEDs) in sample B. Therefore, it is reasonable to assume that chips with LSDs like those in samples C and D are at higher risk of high leakage current. Besides, energy dispersive X-ray spectroscopy analysis showed that no excess carbon was detected, proving no carbon-inclusion contained in samples. The detailed evaluation results were summarized in Table 2.

In conclusion, we assumed that LSDs resulting from scratch, PL-black and unknown (sample A, B and D) are more likely to be killer defects for reverse voltage application. To reduce LSDs, the quality improvement of substrate seemed to be fundamental, and currently shallow surface defects, such as scratch, carbon-inclusion, BSF and PL-black, could be detected successfully. However, LSDs like sample D could only be evaluated after epitaxial, because the nondestructive inspection method of dislocation with high accuracy and high throughput is still under development.

Summary

Our research on the investigation of various LSDs revealed that these defects totally resulted from the substrates and accompanied with stacking fault defects and threading dislocation lines during epitaxial growth. Although particle defects have been reduced remarkably by advancing epitaxial growth technology, epitaxial defects resulting from the substrate are still inevitable, and some LSDs may turn out to be killer defects. Therefore, it is important to reduce defects and threading dislocations in substrates and to develop a nondestructive method for wafer screening.

References

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