

PL Signatures from Decoration of Dislocations in SiC Substrates and Epitaxial Wafers

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Abstract. Photoluminescence (PL) signatures of 4H-SiC substrate and epitaxial wafers from a surface inspection tool have been studied. Large variations in PL black or white dot densities were confirmed for comparable crystal quality and growth process conditions. Comparison with KOH etching results confirms that both PL black and white dots are tied to discrete threading dislocations. PL spectra results suggest dislocation decoration by donor-acceptor pairs.

Introduction

Silicon carbide (SiC) technology can help maximize the efficiency of power systems and simultaneously reduce their size, weight, and cost as compared to legacy silicon based systems. Demand and market size projections for SiC based systems continue to grow significantly. Recent forecasts predict that the SiC device market will grow beyond \$6 billion by 2027 from \$1 billion in 2021 [1]. Applications in discrete power devices for energy efficiency, power inverters & regulators, and 5G communications are pulling the SiC market size projections. Demand from the global automotive market for 150mm SiC wafers will also grow to 1.69 million units by 2025 [2]. Fast and accurate wafer defectivity inspection in the wafer production line is one of the most critical factors for high volume manufacturing of SiC wafers. To gain broader market acceptance, better defect control and reliable surface inspection are required for SiC wafer production. In-line surface inspection tools with photoluminescence (PL) capabilities have been introduced in the SiC wafer industry to detect and count crystal defects accurately for both substrate and epitaxial SiC wafers [3, 4]. In this paper, dislocation signatures in PL images from a surface inspection tool will be investigated by correlation with KOH etched images and PL spectra.

Experimental

4H n-type crystals were grown by the PVT process. Industry standard wafering, grinding, slicing, and epitaxial growth techniques were also employed for substrate/epitaxial wafer generation. Dislocations were measured by counting etch pits formed at the intersection of dislocations with wafer surfaces following immersion in molten KOH. KLA Candela 8520, Lasertec SICA 88, and Etamax MiPLATO tools were used to inspect wafer level defectivity. Table 1 shows specifications for the different surface inspection tools. SICA NIRW PL images are taken from the excitation at 313 nm and the NIRW filter (660nm-long pass).

Table 1. Specifications for three surface inspection tools.

Company	Lasertec	KLA	EtaMax
Model	SICA-88	Candela CS8520	MiPLATO-SiC
Scan method	X-Y with TDI camera	R-Theta with PMT	R-Theta with PMT
Detection method	PL 2 ch & Surface (confocal+DIC)	PL, reflection & scattering	PL 3 ch/Surface/Spectrum
Light source	Hg-Xe lamp	355 nm normal laser	Laser
	Surface : 546nm	405 nm oblique laser	Surface : 355nm laser DIC
	PL : 313nm/365nm		PL : 355nm

Results and Discussion

SICA NIRW PL images from substrate and epitaxial wafers in Fig. 1 show black dots while surface reflection images, which are very sensitive to surface topological defects, are very clean. Large variations in the density of PL black dots were observed for comparable dislocation densities and crystal qualities in both substrate and epitaxial wafers. Non-radiative recombination centers along the dislocations formed by decoration of point defects/dopants were reported for the decoration mechanism [5] and the combination of matrix light absorbance and dislocation decoration have been proposed to explain large variations in dislocation visibility from the surface inspection tool [6]. Most bulk and epitaxial growth conditions and crystal quality metrics don't exhibit correlation with the density of PL black dots. Many of the PL black dots from epitaxial wafers originate from substrate wafers as shown in Fig. 2. Some PL black dots from substrate wafers generate traditional epitaxial defects such as triangular and carrot defects.

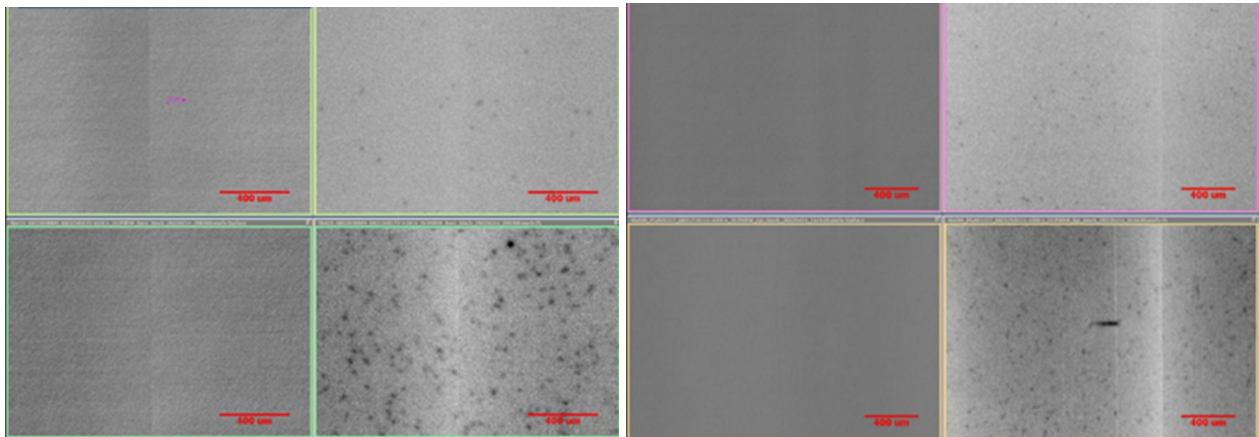


Fig. 1 SICA 88 images from substrate (left) and epitaxial (right) wafers. In each group, images on left and right are surface (specular reflection) + and PL NIRW (313 nm + NIRW filter) images, respectively. Two different wafers with comparable crystal qualities show very different PL black densities in each group. Scale bar is 400 μm .

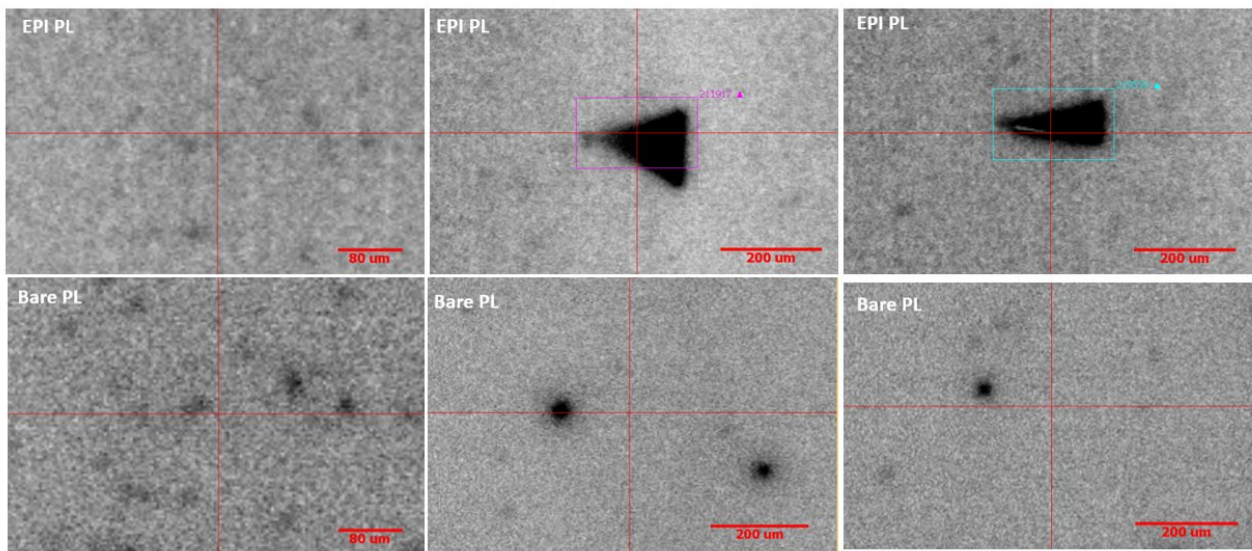


Fig. 2 SICA NIRW PL images from substrate (bottom) and epitaxial wafers (top) of the same areas.

Comparison with KOH images (Fig. 3) shows good correlation between PL black dots and discrete threading dislocations. No correlation is observed with BPDs. There is, however, no strong correlation between black dot size/contrast and dislocation types. PL white dots from substrate wafer NIRW images were also compared with KOH etched surfaces as shown in Fig. 4. Most PL white dots without surface specular reflection signatures are correlated with discrete TEDs. The density of PL white dots varies significantly for wafers with comparable substrate and epitaxy qualities.

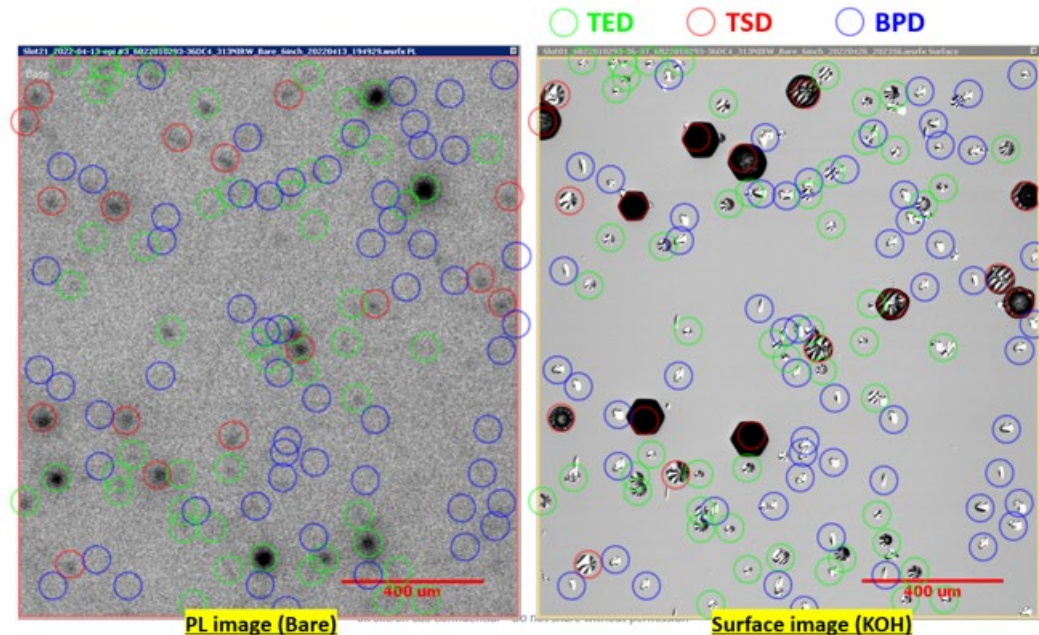


Fig. 3 SICA NIRW PL (left) and KOH etched surface (right) images from substrate wafers

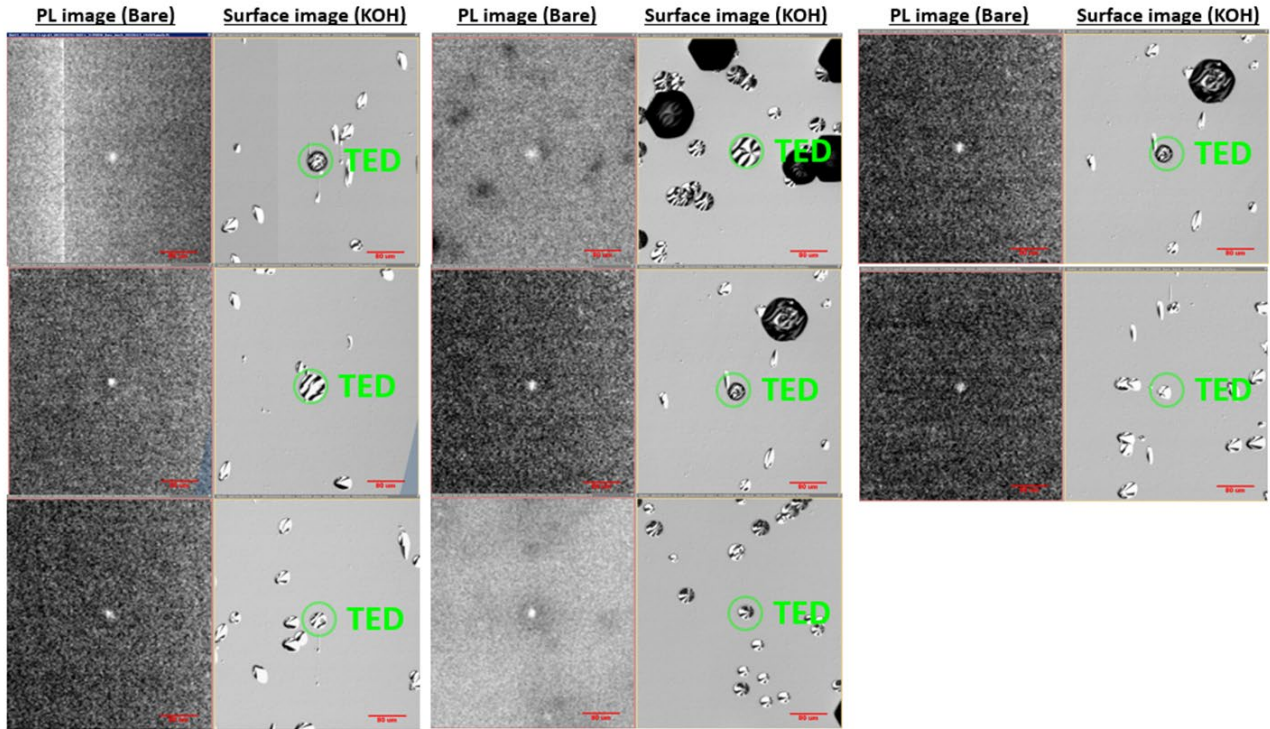


Fig. 4 SICA NIRW PL (left) and KOH etched surface (right) images from a substrate wafer. Scale bar is 80 μm .

To understand the roles of dopants/point defects in dislocation decoration for PL black and white dots, room temperature PL spectra were obtained from high and low PL black and white dot density areas of epitaxial wafers as shown in Fig. 5. A PL peak near 390 nm from the band edge emission is observed for all areas. A broad band from 450 nm to 700 nm may be related with the nitrogen donor-boron acceptor recombination related emission [7]. NcVsi centers characterized by the peak around 1300 nm [8] are not associated with this band. High PL intensity from the broad band (450 to 700nm) is observed for high density PL black and white dot areas.

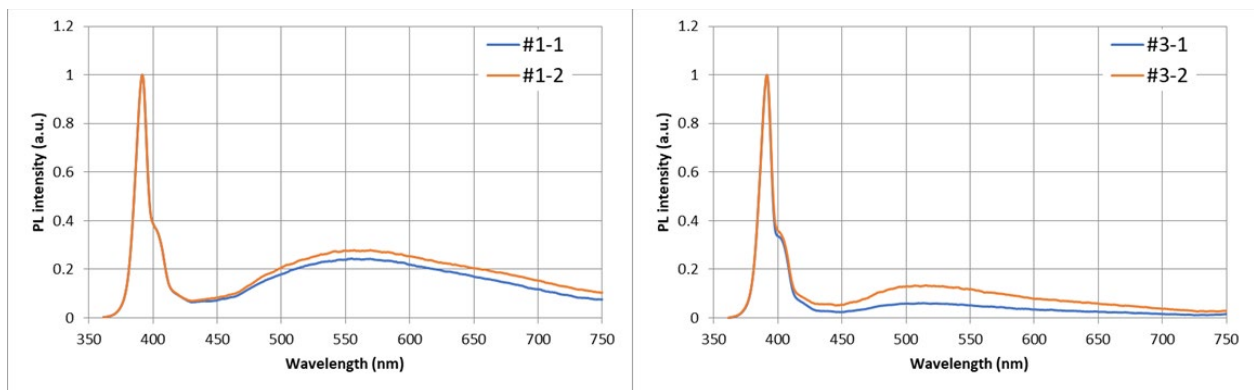


Fig. 5: PL Spectra at different areas of epitaxial wafers by the Etamax spectrometer tool.

#1-1: low density black dot area, #1-2 : high density black dot area

#3-1: low density white dot area, #3-2 : high density white dot area

Summary

Large variations in PL black or white dot density at comparable crystal qualities and growth conditions were confirmed for both substrate and epitaxial wafers. There is no clear correlation between PL black/white dots and growth process parameters. Comparison with KOH images

confirms that both PL black and white dots are tied to discrete threading dislocations. Dislocation decoration by donor-acceptor pairs is suggested, but further study such as elemental analysis on decorated dislocations or low temperature PL study for decoration mechanism is required.

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