In the last several years, a large number of research and development groups have demonstrated remarkable silicon carbide device results that were made possible by effectively leveraging the exceptional fundamental materials properties of silicon carbide (SiC). Such demonstrations of capability are very exciting and have driven many of these groups to begin offering commercial silicon carbide devices. Yields and costs become pivotally important since commercial success demands providing customers with reliable, high performance components at acceptable prices. To that end, knowing the defect distributions in SiC substrates and how they interact during epitaxy growth is vital in the development and production of high quality substrates for epitaxy and devices. For SiC substrates, not only is it important to know the standard bulk defect densities, e.g. micropipes (MP), basal plane dislocations (BPD), threading edge dislocations (TSD) and threading screw dislocations (TSD), but one must also anticipate the surface features and epitaxy defects these bulk defects can induce.

Modern optical characterization tools can quickly generate full wafer maps of defect distributions and these maps can help drive continuous defect density reductions in SiC substrates. For example, Cree has demonstrated the ability to map the distribution of BPD’s, TSD’s and TSD’s in KOH etched substrates using the Lasertec SICA6X. Successful mapping is only possible with reference to extensive etch feature catalogs that were developed by comparing x-ray topography of these dislocations in substrates to resultant etch features in the substrate [1]. These image catalogs form the basis of our automated counting of dislocations in the substrates, producing full wafer maps (and images). For each characterized crystal, the dislocation density and distribution of each wafer is interpolated from analysis of sacrificially etched wafers from the crystal. In addition, each individual SiC substrate is also mapped after processing to characterize features in the bare substrate surface (i.e. scratches, etc) and if applicable, surface features of epitaxy on the wafers (carrots, particles, etc.).

For this work, the density and locations of defects, such as TSD’s, throughout any given crystal are estimated based on optical characterization of etched sacrificial wafers taken from the crystal. This estimation predicts both the axial trend along the crystal as well as the distribution across the surface of prepared wafers. We find that the locations of features actually found on the surfaces of the remaining wafers or on epilayers grown on the remaining wafers correlate well to the estimated locations and density of defects in the substrate developed through our benchmarking. We attribute this consistency to the fact that the defects do not drastically change position or density wafer to wafer. **Fig 1** demonstrates the ability to spatially overlay extended defect positions with surrounding substrate defects from bare wafer and sacrificial etched wafer characterization. Blending this approach with statistical techniques, enabled by our high volume, we aim to accomplish: 1) continued quality improvements; 2) predicting yields in manufacturing; 3) developing specifications on product wafers.

We consider the probability of developing epitaxial defects from pre-existing defects in substrates based on dislocation densities and their spatial distribution in the substrates. We will specifically discuss the carrot defect formation mechanism proposed by Zhang et al. [2] that suggests a carrot defect can arise from the interaction between a threading screw dislocation and a basal plane dislocation in $4^\circ$ off-axis 4H SiC epitaxial growth, and investigated by morphological features in [3]. **Fig 2** shows a typical epitaxy wafer carrot defect distribution. **Fig 3** shows the
The distance of the estimated TSD location to the location of the carrot defect. We will describe a rigorous comparison of the density and distribution of substrate TSD and BPD to the density and distribution of carrot defects in epilayers grown on those substrates.

**Fig 1.** Overlay of optically characterized features in a 3mm radius area from an epitaxy wafer showing positions of carrot defect (C) and the TSD (T), BPD and TED dislocations from a sacrificially etched wafer in proximity to the epitaxy wafer. A carrot and TSD are overlapped in center. In this 3mm diameter, the localized dislocation densities are TSD=99 cm$^{-2}$, BPD 1797 cm$^{-2}$, TED 636 cm$^{-2}$.

**Fig 2.** Full wafer spatial distribution of carrot defects on an epitaxy wafer characterized by Lasertec SICA6X. Typical carrot defect shown to the right for 30μm epilayer.

**Fig 3.** Histogram of the minimum distance from a carrot defect to TSD, in the same wafer of Fig 2. The full wafer TSD density is 323 cm$^{-2}$.

**References**

