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Improvement of the Conformational Stability of 150 mm 4H SiC Wafers

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Abstract. A method for mitigating loss of conformational stability in 150 mm n-type 4H SiC wafers was investigated. Modifications to the physical vapor transport (PVT) process used to grow the parent bulk crystals, combined with post-growth thermal treatment, were examined as means of reducing the internal stresses hypothesized to promote instability. The magnitude of the stresses was analyzed by mechanically thinning sets of wafers produced from each process to determine the critical thickness of stability loss. The average critical thickness was found to be reduced by 13% via growth cell modification, at a reduced level of thermal treatment relative to a control process, with all wafers becoming unstable greater than 30 μm below the minimum recorded production thickness. Assessment of the spatial uniformity of dislocations indicated that lower conformational stability corresponded to elevated densities of basal plane dislocations (BPDs) and threading edge dislocations (TEDs) at the wafer edge relative to the center.

Introduction

Increasing demand for 4H n-type SiC wafers due to the rapid expansion of the electric vehicle market has led SiC manufacturers to seek ways to improve production output. One approach has been to increase bulk crystal lengths by enhancing the deposition rate of the PVT process that is standard to the industry. The process modifications necessary to achieve the target growth rates, however, can introduce undesired stresses that manifest after downstream fabrication steps. In particular, an unstable wafer conformation characterized by a low energy barrier to bow inversion has been observed after post-growth machining. Instability in the state of bow and warp is a challenge to wafer production as it complicates robotic handling, and can disrupt epilayer deposition. [1] This study investigated a bulk growth process adjustment that was intended to reduce the incidence of conformational stability loss, with focus on an examination of the spatial distributions of dislocations and nitrogen doping, which have been identified as potential origins of internal strain. [2,3]

Experimental

A PVT technique was used to grow 4H n-type SiC crystals, which were processed into 150 mm wafers using well-established grinding, slicing and polishing techniques. Modifications were made to both the components holding the seed and the growth volume to impact the stress distribution of the grown crystal. The modifications were combined with post-growth thermal treatment steps such that three processes were tested: modifications + level 1 (reduced) thermal treatment (process A); modifications + no thermal treatment (process B); and no modifications + level 2 thermal treatment (control, process C). Wafers from each process were thinned until their conformations became unstable to measure the critical thickness of stability loss. Overall defect densities were measured using a KOH immersion technique to selectively etch the points of intersection of dislocations with the wafer surface. Basal plane dislocation densities were qualitatively assessed using $(11\overline{2}8)$ x-ray topograph reflections (Rigaku XRTMicron). A contactless eddy current technique was used to indirectly evaluate the concentration of nitrogen dopant atoms by measuring resistivity.

Results and Discussion

Wafers were selected from several axial positions within crystals belonging to each of the three trial processes and thinned in increments of 20 µm. The critical thickness trends for each process with respect to normalized axial position are shown in Fig. 1 (a). Conformational stability of process A

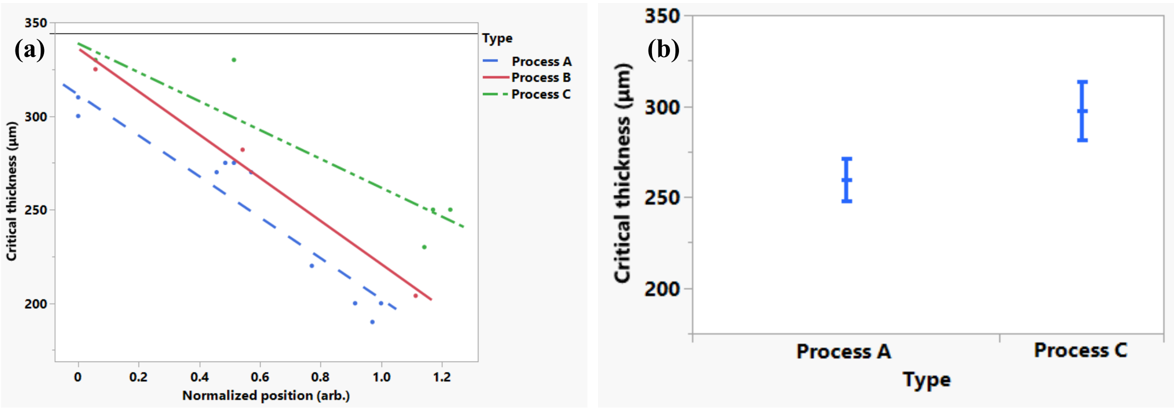

Figure 1. (a) The critical thicknesses at which wafers selected from trial processes A, B and C lost conformational stability as a function of normalized axial position. A linear fit was applied to each dataset. The horizontal line indicates the minimum average thickness recorded for over 25,000 production wafers. (b) Mean critical thicknesses for processes A and C, with error bars representing the standard error of the mean. N = 15, 3 and 8 for processes A, B and C, respectively.

wafers was observed to be lost at a reduced thickness with respect to processes B and C over the entire range of axial positions. The mean critical thicknesses for processes A and C, shown in Fig. 1 (b), were calculated to be 260 µm and 298 µm, respectively. These results indicate that the growth cell modification was sufficient to relieve the internal stresses hypothesized to be responsible for conformational instability, as the reduced thermal treatment of processes A and B would be expected to be less effective than that received by process C. The positional dependence of the critical thickness is attributed to the axial temperature gradient that drives mass transport in the PVT process.

The instability of bow and warp at reduced thickness is considered to have the same basis as the Twyman effect, in which the radius of curvature of wafers of many materials has been observed to decrease with decreasing thickness due to unbalanced surface stresses. [4] In general, the flexural rigidity of circular plates is a strong (cubic) function of thickness. [5] In the present study, two mechanisms responsible for internal stress were considered: inhomogeneous distributions of dislocations and/or nitrogen dopant incorporation. To investigate whether the differences in critical thickness were due to the former, contour maps of threading screw dislocations (TSDs), TEDs and BPDs measured for representative wafers from similar relative positions within the crystal were compared.

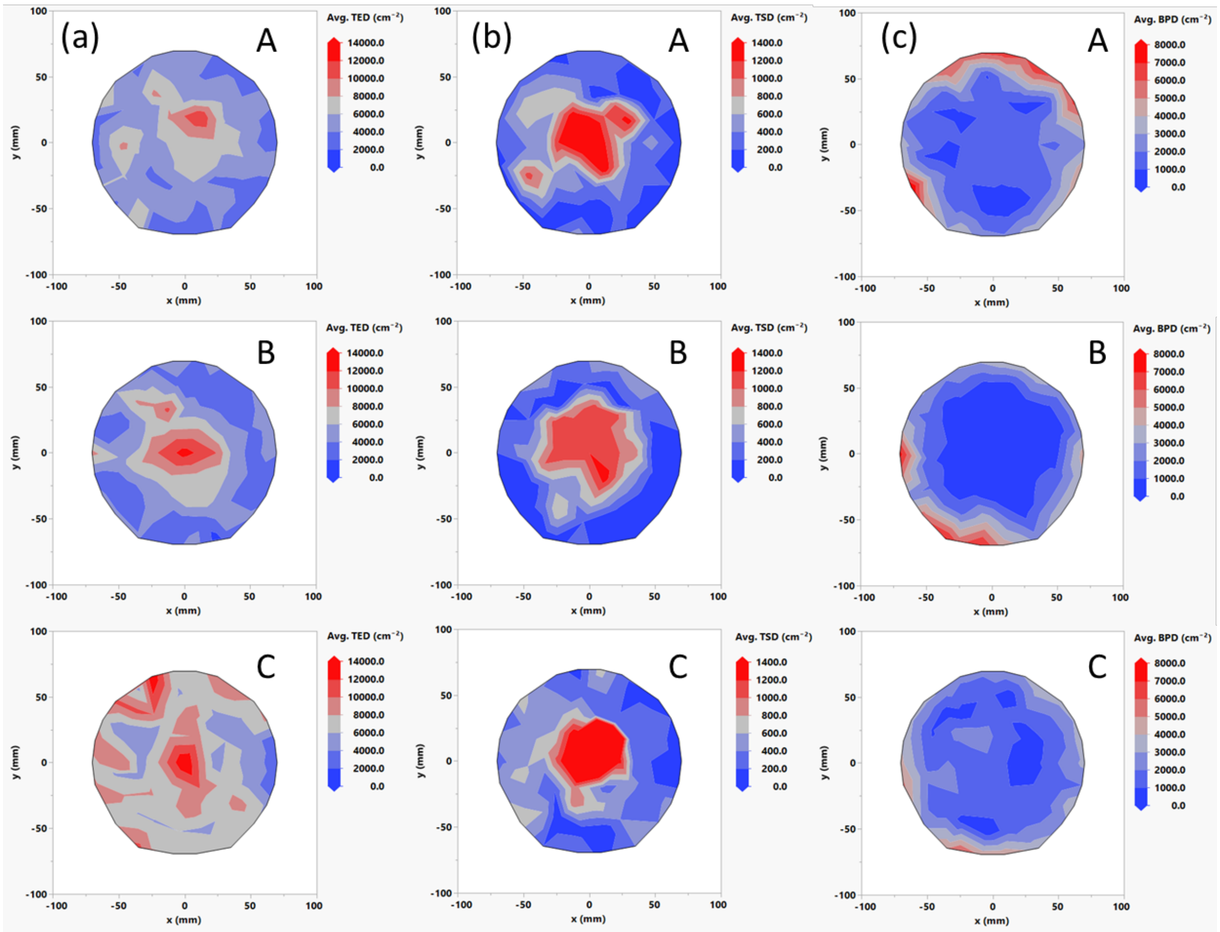

Figure 2. Contour maps of the TED (column (a)), TSD (column (b)), and BPD (column (c)) densities measured for representative wafers from processes A, B and C as indicated in the upper right of each plot.

Columns (a), (b) and (c) of Fig. 2 show TED, TSD and BPD distributions for the indicated processes, respectively. These maps show no clear trend in critical thickness with TSD configuration. The control process wafer exhibited a high TED density around the periphery with respect to the wafers produced from the modified processes. Interestingly, the wafer that did not receive thermal treatment (column (c), process B) exhibited high concentrations of BPDs around the edge, whereas the two that did (column (c), processes A and C) showed more even distributions and lower edge BPD densities, with process C exhibiting the lowest edge concentration. This would suggest a reconfiguration of BPDs to reduce overall wafer stress. It may be concluded that, as process A showed the lowest critical thickness for instability, it is a combination of low peripheral TED density and uniform BPD distribution that most strongly promotes conformational stability.

The spatial distributions of resistivity values measured for representative wafers from each process (identical to those included in Fig. 2) are shown in Fig. 3. A recent study [6] had found evidence that the elastic modulus of the bulk crystal increased with increasing resistivity (lower nitrogen concentration), which correlated to reduced conformational stability. If there is indeed a relationship between elastic modulus and stability, the relatively high resistivity exhibited by the process A wafer (Fig. 3 (a)) would suggest that the growth modification that was applied for that process mitigated the impact of the reduced nitrogen concentration, as it was seen to be the most stable in terms of critical thickness. In particular, a reduction edge TEDs and the associated strain would offset the elevated elastic modulus, in turn reducing stress. Otherwise, the relative overall resistivity values of the process B and C wafers confirm the hypothesis that reduced nitrogen doping promotes conformational instability.

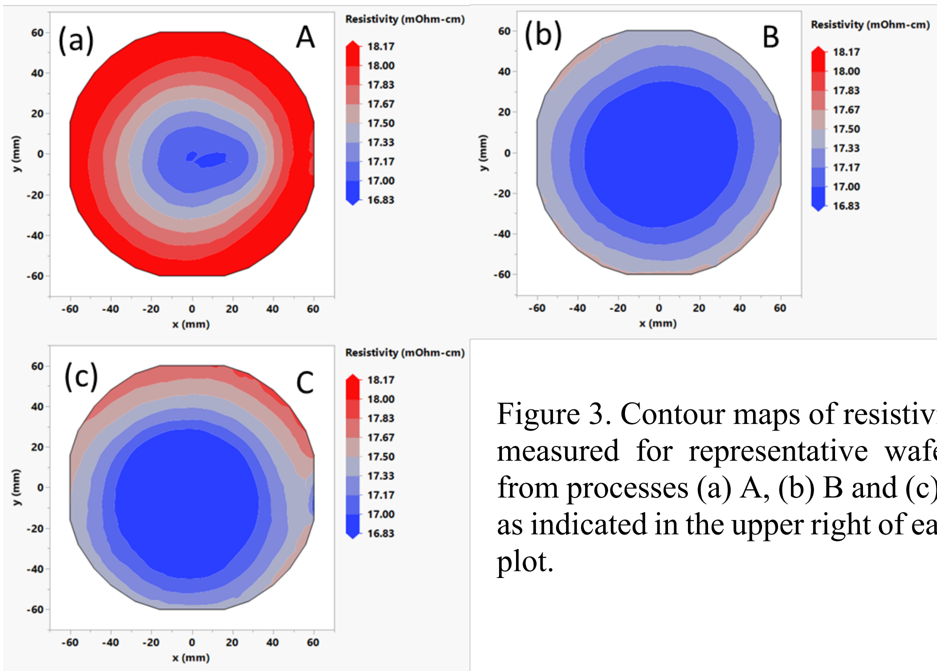

Figure 3. Contour maps of resistivity measured for representative wafers from processes (a) A, (b) B and (c) C as indicated in the upper right of each plot.

To provide a more thorough assessment edge defectivity than that possible by KOH EPD analysis, wafers from processes A and B were scanned using an in-house x-ray topography tool in radial bands from center to edge in the $[\mathbf{11\bar{2}0}]$ direction. Seed and dome end wafers were included for process B (Fig. 4 (b) and (c), respectively) to compare the effect of position within the crystal to the impact of thermal treatment. In the corresponding images, shown in Fig. 4, white contrast indicates the presence of dislocations (dominated by BPDs), while dark contrast represents the background.

Comparing (a) and (b) (modified growth process with and without thermal treatment, respectively), it is apparent that thermal treatment promotes a uniform BPD distribution; more defects inhabit the region indicated by the dashed lines. This confirms the result obtained from counts of etch pits. Notably, the wafer shown in (c), taken from the dome end of the modified process that did not receive thermal treatment, has significantly fewer dislocations across the entire scan area. This indicates that position within the bulk crystal has a much stronger impact on BPD distribution and conformational stability than the application of thermal treatment.

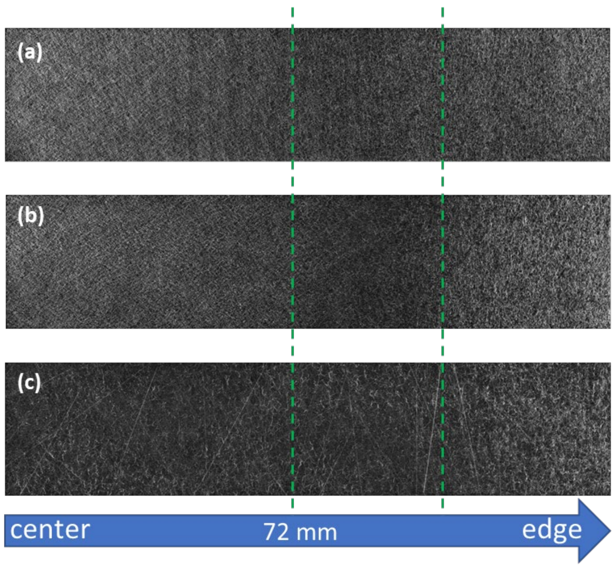

Figure 4. Inverted contrast Cu $(11\bar{2}8)$ XRT scans from wafer center to edge along the $[11\bar{2}0]$ direction for representative wafers from (a) process A seed end, (b) process B seed end, and (c) process B dome end. Vertical dashed lines are a guide to the eye.

Summary

A PVT crystal growth process was developed to reduce the incidence of conformational stability loss observed for 150 mm wafers. Modifications to the growth cell and application of thermal treatment steps were tested. Wafers from each process were ground in successive thickness increments until stability was lost, to test the hypothesis that stability depends on the magnitude of internal stresses. The best performance was obtained with a modified growth cell in addition to reduced thermal treatment. XRT and KOH EPD analyses were performed to assess the impact of resulting dislocation distributions on process performance. It was found that higher conformational stability associated most strongly with position of the wafer within the crystal, with spatial uniformity of BPD density being a secondary factor. Modifications to the growth cell were also found to mitigate any elevation of stress that were presumed due to an increase in elastic modulus associated with reduced nitrogen concentration. Future work will involve further refinement and scale-up of the modified PVT process to improve the reliability of wafer performance.

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