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Strain Relief of Silicon Carbide Substrates (4H-SiC) by Wet Etching

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Abstract. Strain relief etching is a critical wet process technique use in high volume manufacturing of semiconductor substrates and device wafers. The goal of a strain relief etch is application dependent but can generally be considered for removal of warp/bow or improving mechanical strength by removing sub-surface damage thereby optimizing yields. Silicon Carbide (SiC) has a high chemical resistance which has blocked SiC wafer manufacturers from using strain relief etching to date. In this work, we demonstrate strain relief etching using an Advanced Chemical Etching (ACE) process of the full wafer surface on commercial grade 4H-SiC wafers and poly-SiC wafers at high etch rates (µm's/hr) which enable ACE as a production technique. The data shows a 4 times improvement of breakage strength, from 13 to 55N, in laser split wafers. Bow and warp of ground wafers is reduced from 70/250µm to -5/25µm approx. respectively, matching Chemical Mechanical Polished (CMP) wafers which is the industrial method for preparing wafers. Thus showing the potential of stronger, flatter wafers being available for chemical mechanical polishing.

1 Introduction

Wet chemical etching is a well-established process in the semiconductor industry, particularly for silicon-based wafer manufacturing. It plays a key role in device fabrication, substrate preparation, and surface conditioning due to its scalability, controllability, and compatibility with high-volume manufacturing. However, extending this technique to wide bandgap semiconductors such as silicon carbide (SiC) has proven challenging due to SiC's exceptional chemical inertness. As a result, SiC substrates typically undergo aggressive mechanical processes—such as grinding and polishing—to achieve the desired thickness and surface flatness. These techniques can introduce significant sub-surface damage, residual stress, and wafer bow or warp, especially early in the manufacturing line when wafers are thin and fragile[2, 3]. Use of extensive mechanical techniques is also expensive and difficult to perform at volume where wafers are fragile early in the substrate manufacturing line. Research has explored mechanisms of wet etching for creating microstructures on 4H-SiC[4] and trenches in 6H-SiC [5].

ACE performs wet etching of 4H-SiC in an innovative approach. The ACE technology allows controlled material removal in a single-sided processing set-up with no edge exclusion with material removal rates between 15 and 20µm/h.

We also postulate that one of the primary applications of ACE on SiC wafers is strain relief etching, where the removal of damaged and strained surface layers leads to reductions in bow and warp, and a marked improvement in mechanical strength. This is particularly beneficial prior to downstream steps such as chemical mechanical polishing (CMP), where wafer flatness and stress state directly impact process yield and wafer survival.

In this study, we investigate the effects of ACE strain relief etching on commercial-grade n+ type SiC wafers. The focus is on providing evidence of the strain-relieving properties of the ACE and quantifying any improvements in mechanical strength and wafer shape (bow/warp) achieved through ACE processing. A combination of metrology techniques is used to characterize the impact of the process.

2 Methodology

Sample Description

Samples were obtained from SiC wafer manufacturers, which have undergone wafer cutting with wire-sawing or laser-splitting and coarse grinding. Wafers were 150mm in diameter, nominally (0001) orientated with a 4 deg offcut, 350 µm thick and doped with Nitrogen so that the resistivity was 10-20 mOhm.cm. In addition, wafers after laser-splitting were processed as well. Finally, 4H monocrystalline wafers as well as poly-SiC substrates both thinned with backside-grinding were obtained from another commercial supplier.

Characterization Techniques Used

To assess the strain relief and damage removal capabilities of ACE on 4H-SiC wafers.
Stress/Strain was compared using:

- Laser scatterometry (Onto Primascan) for visualization of grinding-induced surface damage.
- X-ray topography (XRT) using the Rigaku Micron 3-300 in reflection mode to assess subsurface strain. Instead of typical plan view images, cross sectional images were obtained to demonstrate the surface effect.

Thickness of removed material was measured by weighing the wafers before and after the etching with a laboratory scale. Wafer breakage strength was measured on a 3-point bending set-up.

3 Results and Discussion

Here we characterise ACE etching on three important components of SiC technology: 1) standard processing of monocrystalline wafers, 2) new laser split monocrystalline wafers and 3) device wafers which are thinned as the final step on both monocrystalline and polycrystalline wafers.

Impact of ACE on Strain in Ground Monocrystalline 4H-SiC Wafers

In this section we show the comparison of laser scatterometry images and XRT images captured in reflection mode before and after the 3 µm ACE etch on commercial coarse ground 4H-SiC wafers

Laser Scatterometry

Prior to etching [Fig. 1a], the typical wafer surface displays a dense pattern of radial grinding marks, typical of mechanical thinning processes and indicative of residual surface stress and microcracking. After etching [Fig. 1c], these features are significantly reduced or eliminated, suggesting effective removal of the mechanically damaged surface layer. This result implies a more uniform surface stress profile and is consistent with strain relief from the etching process.

Subsurface Strain Mapping with XRT

The pre-etch wafer [Fig. 1b] exhibits a dark linear feature near the surface—this line corresponds to a region of high strain effects introduced by coarse grinding. After the 3 µm ACE etch [Fig. 1d], this feature is completely absent, suggesting that the strained layer has been removed and the near-surface lattice has relaxed. This behaviour is additionally underlined by the XRT cross section scan [Fig. 1e]: while the scan of the ground wafer exhibits large strain peaks close the the wafer surface, these are reduced almost down to bulk level in the etched wafer.

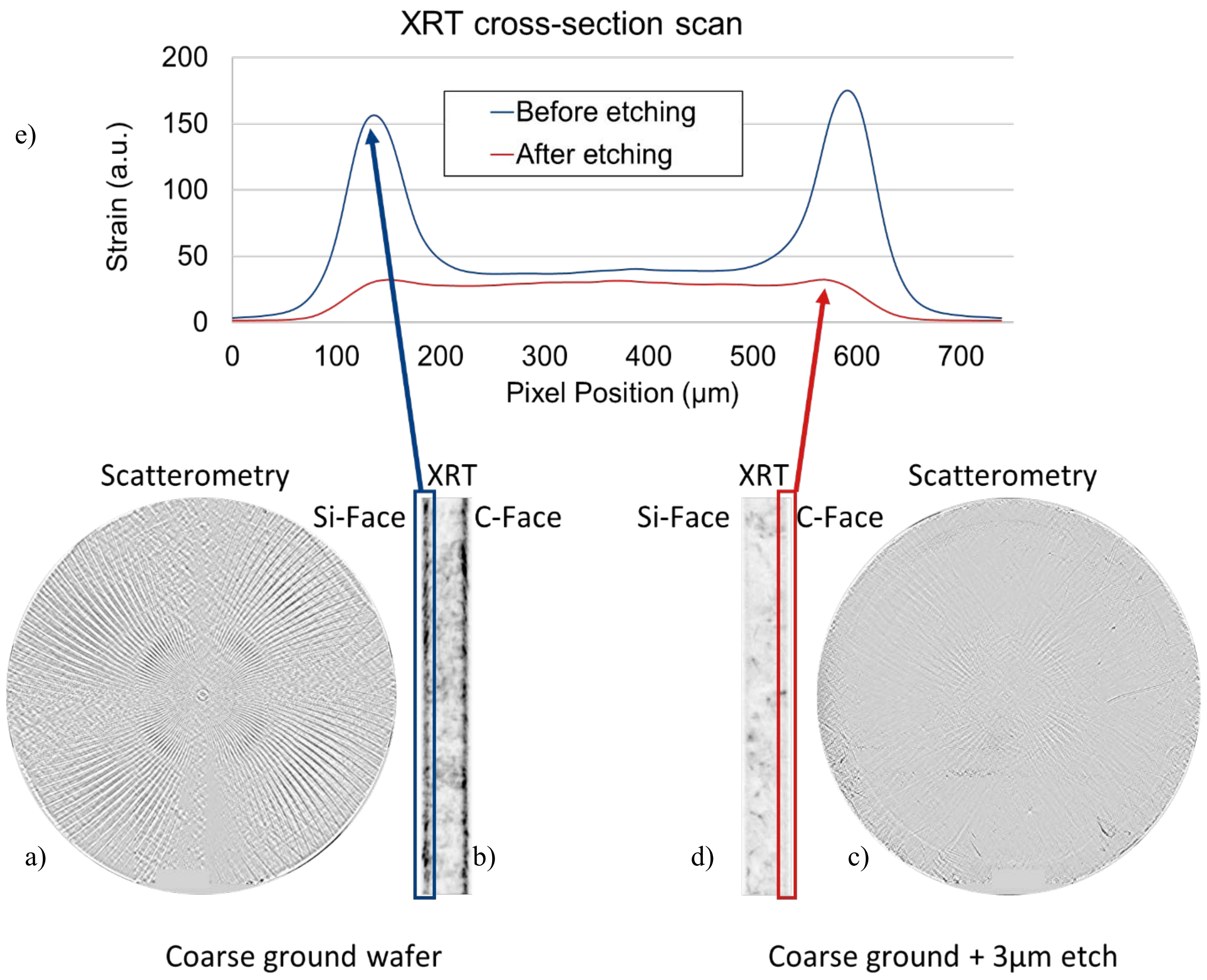

Fig. 1. Laser scatterometry images of 6” SiC wafers (a) before and (c) after 3 µm ACE etching. Grinding marks are largely diminished post-etch, indicating reduced surface strain and damage. Cross-sectional XRT images (b) before and (d) after 3 µm ACE etching. The high-strain layer present in the unetched wafer is fully relieved post-etch. Large peaks witnessing the high amount of sub-surface strain after grinding in the XRT cross-section scan (e) almost completely disappear after etching.

Enhancement of Mechanical Strength on Laser Split Monocrystalline 4H-SiC Wafers

To evaluate the mechanical benefits of ACE following laser splitting, a batch of 6-inch 4H-SiC wafers was subjected to ACE etching with a removal depth of 5 µm. The mechanical robustness of the as split and etched wafers was assessed via 3-point bend breakage testing. For comparison, a control group of wafers underwent coarse backside grinding instead of ACE etching.

Figure 2 presents the break force results across the three conditions: post-laser split (no treatment), post-coarse grind, and post-ACE etch. The as-split wafers exhibit low break strength, with values around 13 N. Following ACE etching, the breakage force increases by a factor of four, reaching values above those achieved by coarse grinding (~40 N vs. ~50–60 N). This substantial improvement indicates that ACE etching effectively strengthens the wafer against mechanical failure, likely by smoothing out the sharp surface features of the post-laser-split surfaces.

This indicates that integrating a 5 µm ACE etch immediately after laser splitting can significantly improve wafer robustness and reduce breakage rates in subsequent handling or grinding operations.

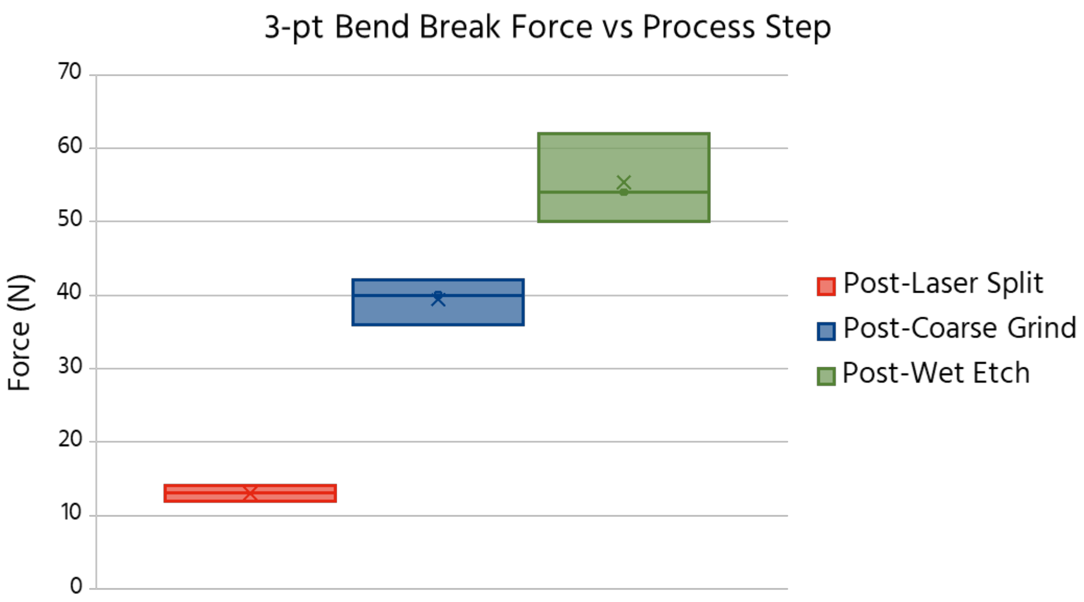

Fig. 2. 3-point bend break force measurements for SiC wafers after laser splitting, after coarse grinding, and after 5 µm ACE etching. ACE-treated wafers show the highest mechanical strength.

Reduction of Bow and Warp Through ACE Etching After Grinding

To assess the impact of ACE on wafer shape distortion, 25 6-inch SiC wafers were first subjected to frontside (Si face) grinding. The wafers were then split into two groups: Group A (20 wafers) underwent ACE etching with a removal depth of 5 µm, while Group B (5 wafers) was processed through chemical mechanical polishing (CMP) as a control.

Figure 3 illustrates the evolution of bow and warp through the sequence of process steps. After grinding, wafers show significant shape distortion, with bow values exceeding 100 µm and warp values reaching ~250 µm. However, after ACE etching, both bow and warp are reduced to levels comparable to those achieved with CMP.

This significant reduction in mechanical distortion confirms that ACE etching effectively removes the stressed and damaged surface layer introduced by grinding. By eliminating this strain, ACE restores flatness and dimensional stability to the wafers and this way provides a better starting point for the following CMP processing.

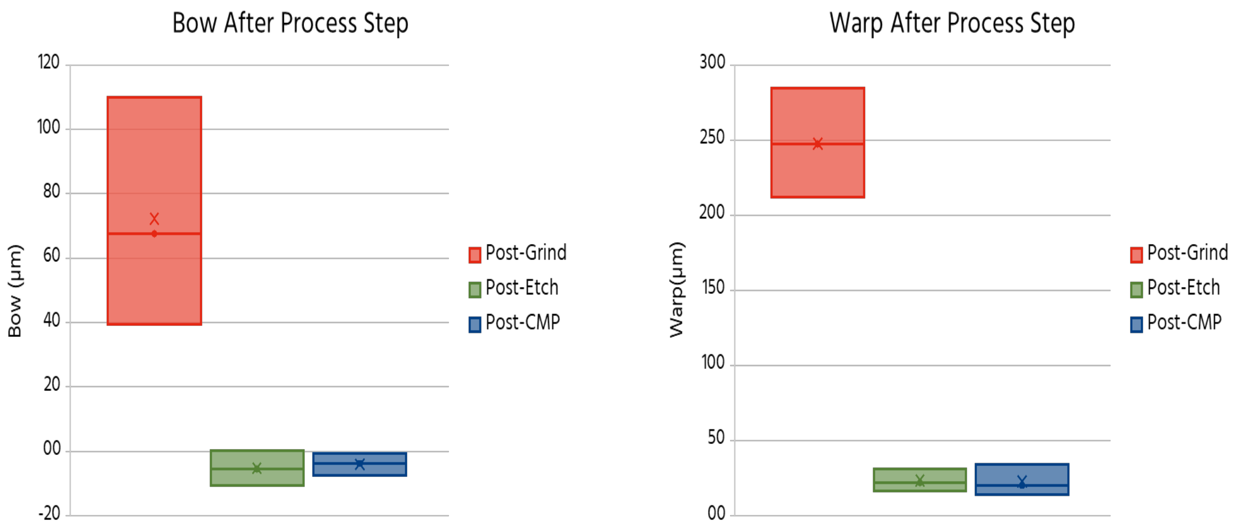

Fig. 3. Bow and warp measurements of 6" SiC wafers after grinding, ACE etching (Group A), and CMP (Group B). ACE etching reduces both parameters to the level of the CMP control group.

Implementation of ACE on Wafers after Backside Thinning

Warp and Bow reduction

To evaluate the effectiveness of ACE etching wafers after backside grinding, two types of 6-inch SiC substrates — 4H-SiC monocrystalline and poly-SiC — were processed. The monocrystalline wafer carried front-side devices, the poly wafer was still blank on both sides. Both were subjected to backside grinding to thin the substrate. Subsequently, a backside ACE etch was performed, removing residual damage.

Figure 4 shows the resulting bow and warp values before and after ACE etching.

- On the 4H-SiC wafer, warp was slightly reduced from 399 µm to 317 µm. However, bow changed significantly — from -202 µm to +315 µm. This suggests that the compressive stress introduced by grinding was effectively removed from the backside, leaving the tensile stress from the front-side device layers dominant. This implies that partial etching, leaving some compressive stress on the backside, might yield a flatter wafer overall.
- On the poly-SiC wafer, both warp and bow were significantly reduced — warp dropped from 886 µm to 85 µm, and bow from -260 µm to +34 µm. This indicates effective stress relaxation and damage removal on this wafer type through ACE.

These results highlight the importance of stress balancing in post-thinning processes and demonstrate the potential of ACE to improve wafer flatness on complex device wafers.

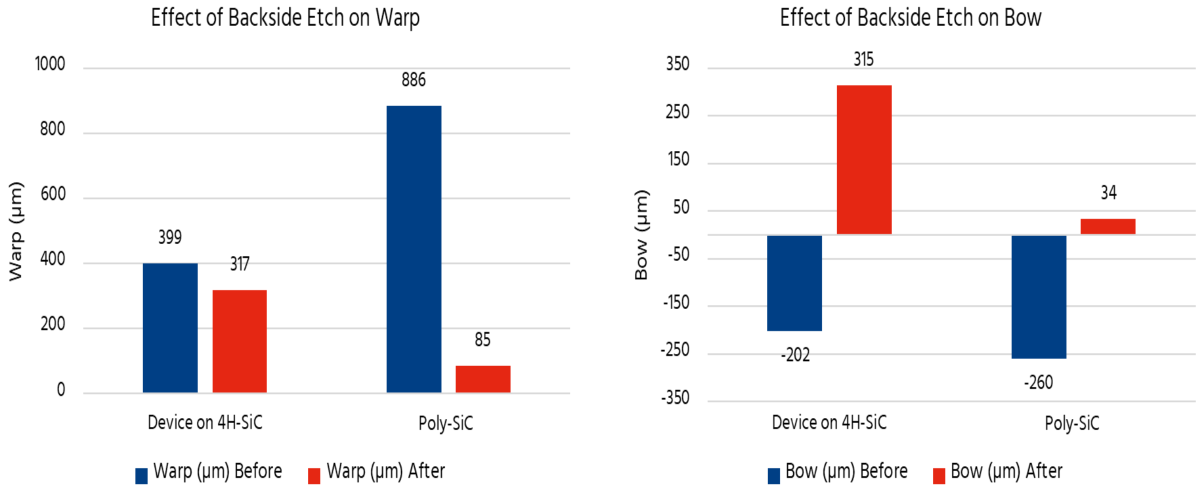

Fig. 4. Effect of ACE etching on warp and bow for 4H-SiC device wafer and poly-SiC substrate after backside grinding. ACE etching leads to significant improvements in flatness, especially on poly-SiC material.

4 Conclusion

ACE technology enables effective strain relief in SiC wafers through wet etching. It significantly improves wafer strength after laser splitting, flattens ground wafers to levels comparable to CMP, and reduces strain-induced distortion in device wafers. Optical and structural characterization confirms the removal of sub-surface damage and residual stress. These findings highlight the potential of ACE for enabling more robust, cost-effective, and high-yield SiC wafer processing. While these findings are encouraging, further work is needed to evaluate long-term device performance and the integration of ACE into high-volume manufacturing environments.

The results demonstrate that ACE etching enables production-scale wet processing of SiC, opening new pathways for cost-effective, high-throughput manufacturing of SiC substrates and devices.

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