Stress Relaxation Mechanism after Thinning Process on 4H-SiC Substrate

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Abstract In this work a comparison between different 6 inches 4H-SiC commercial substrates after post processing has been shown. The main comparison was done between two different suppliers after a thinning process that leaves the sample with a final thickness of 150 microns. After the processing the two substrates show different behavior with different curvature and residual stress. X-Ray diffraction show different crystal quality and curvature values of the substrates. Micro-Raman show different residual stress of the substrates before and after the thinning process. Moreover, molten KOH etching for dislocation detection also show different value of dislocation density for both substrates.

Introduction

Wide band-gap semiconductor materials are attractive candidates for overcoming the limitations of silicon for high voltage/high power devices. Silicon carbide (SiC) is a semiconductor with a wide band gap, high electron mobility, high electron saturation drift velocity and high thermal conductivity.

The combination of electronic and physical properties that silicon carbide (SiC) exhibits make it an excellent semiconductor for electronic devices able to work in hostile environments, where conventional semiconductors like Si or GaAs cannot perform operations.

The critical electric field of SiC is about one order higher than that of Si, which allows much higher doping and thinner drift region layers for a given blocking voltage, resulting in a lower specific on-resistance. This implies that the die size of SiC devices can be trimmed by nearly one order compared with correspondingly rated Si devices [1].

4H-SiC-based device technology has made tremendous progress in recent years owing to the availability of large diameter, high quality silicon carbide boules [2]. The seeded sublimation growth method (modified Lely method) is a widely used technique for growth of single SiC crystals [3].

For SiC wafers to be used in electronic applications, it is mandatory to grow a large SiC boule of a desired single polytype. The substrate study is a crucial point for the technologies development and in the field of high power SiC device, some technologies realization expected the thinning process of SiC substrates. A high value of curvature makes the wafer not workable on different fab tools (ex. photolithography tools). For this reason, in this work, the effect of the mechanical thinning process of the substrates on the wafer curvature and residual stress has been studied.

Experiment Setup

For the experiment we compared two different commercial substrates coming from two different suppliers (named A and B for commercial reason) before and after the thinning process that leaves

the substrates at a final thickness of 150 microns (starting thickness standard commercial 350 microns).

For this experiment, different technique for substrate characterization has been employed, as follow: crystalline and curvature analysis by X-Ray Diffraction, stress analysis by micro-Raman and dislocation evaluation by KOH molten etching.

Results and Discussion

Figure 1a shows the result of the substrate curvature by X-Ray Diffraction analysis via rocking curve position variation method [4]. Rocking curve (rc) line scans was recorded using a Cu-Ka source via a Bruker D8 Discover diffractometer, equipped with an Eulerian cradle and a Ge022 monochromator. The analyses were done on the (0004) 4H-SiC peaks. The position of the peak, instead, changes along the x and y axes (fig.1b), due to the curvature of the wafer. With this method, the radius of curvature (R) can be measured by using the geometric formula:

$$R = \frac{\Delta x}{2} \frac{1}{\sin(\Delta\omega/2)} \qquad\qquad (eq.1)$$

where $\Delta\omega$ is the peak displacement of the rc in the +/- position with respect to the wafer center, and Δx the spatial displacement between a +/- position in the wafer along the x or y axis. Equation 1 for small values of $\Delta\omega$ can be written as:

$$R \approx \frac{\Delta x}{\Delta\omega} \qquad\qquad (eq.\ 2)$$

Due to the linear relationship between the spatial displacement (Δx) and the peak displacement of the rocking curve ($\delta\omega$), the slope of the curves (figure 1a) is the radius of curvature of the sample. The curvature (K) is the reciprocal of the radius of curvature (k=1/R).
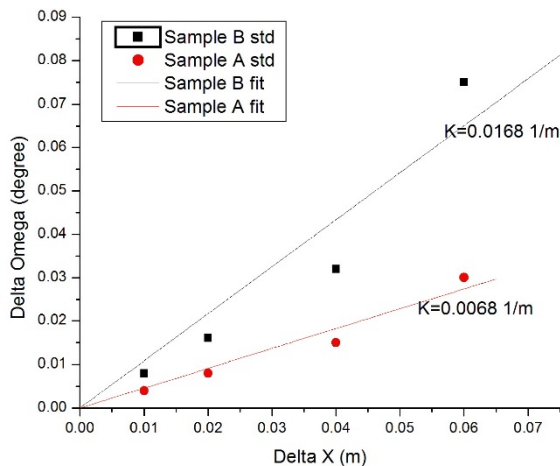

Fig. 1a. XRD curvature via rocking curve (Omega-scan) position variation method. From the slope of the curve is possible to evaluate the curvature value (K).
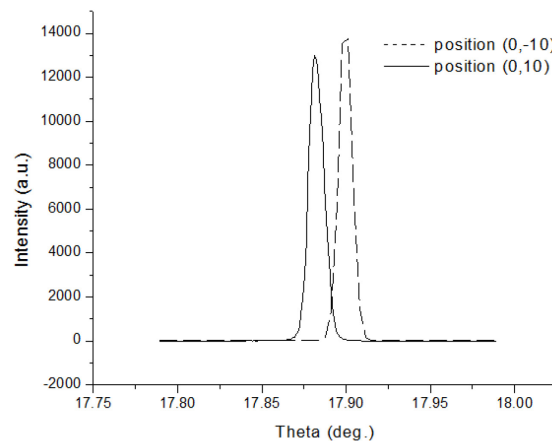
Fig. 1b. Variation of XRD rocking curve position along the wafer diameter due to the curvature.

The analysis shows that, after thinning, the curvature of sample A curvature increase, while in sample B it is almost the same (table 1). Table 1 also reports the value of FWHM of the rocking curve (omega scan) of both samples before and after thinning process. The FWHM of the omega scan is related to the defect density (crystal quality). We found 28 and 29 arcsec for sample B and from 30 to 45 arcsec for sample A, before and after the thinning process, respectively. These results show that the two substrate have different behaviour after the thinning process from curvature and crystalline order point of view.

Table 1. X-Ray diffraction analysis

Sample	Initial		Post thinning	
	FWHM (arcsec)	Curvature (1/m)	FWHM (arcsec)	Curvature (1/m)
A	*28*	*0.0068*	*29*	*0.0122*
B	*30*	*0.0168*	*45*	*0.0175*

The Raman phonon modes shift were measured by micro-Raman spectroscopy using a HR800 integrated system from Horiba Jobin Yvon in a backscattering configuration. The frequency shift of the transverse optical (TO) mode is related to the residual stress fields within the substrate. The excitation wavelength was supplied by a He–Ne laser (632.8 nm) that was focused on the sample by a 100x objective. The measurements show before the thinning a high value of TO mode for the B substrate (high stress) compared to the A one (lower stress). After the thinning, the substrate B decrease the TO value (decrease the stress) while, the A sample is the same. Coupling X-ray diffraction and micro-Raman data analysis, both results show different residual stress relaxation process from substrate B to sample A. The residual stress of sample B seems be released by curvature increasing, while the stress of sample A from the defect increasing.
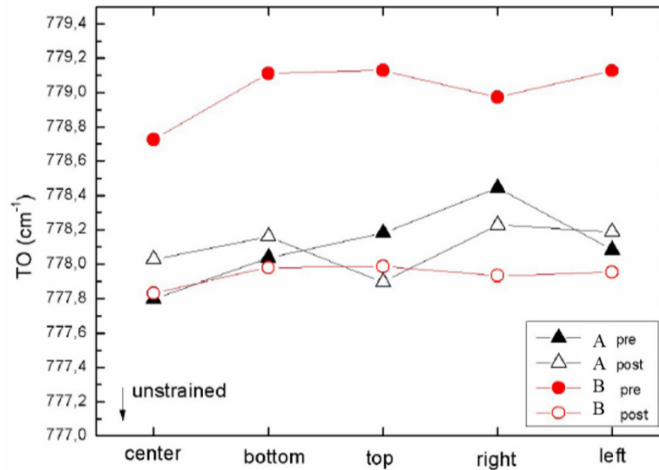

Fig. 2. TO micro-Raman mode of the substrates (A and B) before and after the thinning process.

In order to understand the reason of the different behavior of the two substrates after thinning process, dislocation defects analysis were performed. Usually, structural defects in SiC crystals are revealed by molten potassium hydroxide (KOH) etching [5]. This etching proceeds preferentially at a structural defect position and thus defects such as micro-pipes and all dislocations type as Threading Screw Dislocation (TDS), Basal Plan Dislocation (BPD) and Etch Pit Dislocation density (EPD) appear as etch pits [6]. The destructive KOH analysis was performed with the molten potassium hydroxide (KOH) etching of the surface at 500°C for 5 minutes [7]. Figure 2 show the image of sample B after the etching. In the image are clearly distinguishable the TSDs (hexagonal structures) and the BPDs (small pits). With a powerful software for the image analysis couples with high resolution fully automated (X, Y and Z) optical microscope the number of the dislocations were obtained. From the analysis, the number of dislocations before the thinning process of sample A seems to be double compared to the sample B.

The sample B shows as total etch pit dislocation density (EPD) of about 4500 /cm^2 with BPD 260 /cm^2, while, sample A shows total etch pit density of about 2600 /cm^2 with 180 /cm^2 BPD. The sample A shows similar image with lower etch pit density (not shown). It is known that the dislocation density affect the quality of the material and it also known that the defect density and wafer curvature are related to the residual stress [4]. Different density of dislocation could generate stress gradient that affect the wafer curvature.
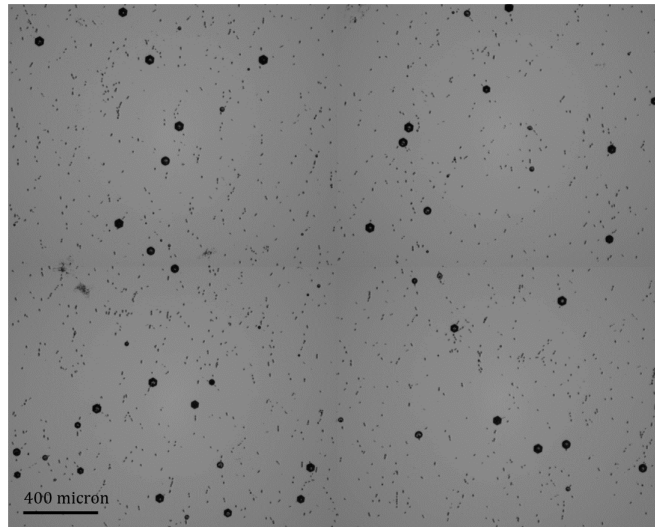
Fig. 3. Example of optical microscope composite image of four scanned zone of the substrate B after KOH molten etching at 500°C for 5 minutes.

Conclusion

All the collected data shows a different residual stress relaxation process that could be ascribed to different temperature gradient inside the bulk growth with the PVT technique. Such temperature gradient could lead to a stress gradient within the substrate [8] that could be released with different concentration of dislocation density and/or curvature of the substrates. A careful study that correlates the increase of wafer curvature with the dislocation density is under investigation.

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