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The Impact of Defect Density on Mechanical Characteristics of 4H-SiC Substrates

Brunella Cafra[1a,*], Nicolò Piluso[1,b], Agata Grasso[1,c], Aye Aye Moon[2,d]
Andrea Severino[1,e]

[1]ST Microelectronics, stradale primosole,
50 95121 Catania, Italy

[2]ST Microelectronics, 629, Lorong 4/6, 319521,
Toa Payoh, Singapore

[a]brunella.cafra@st.com, [b]nicolo.piluso@st.com, [c]agata.grasso@st.com,
[d]aye-aye.moon@st.com, [e]andrea.severino@st.com

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Abstract. In this work the intrinsic and induced defects related to the mechanical strength of 4H-SiC wafer have been investigated by considering substrates having different dislocation density and subjected to different treatments such as thinning process and high temperature bulk and laser annealing. Three point bending test has been performed on die extracted from the substrates in order to calculate the stress σ the die can withstand at breakage (flexural strength). The variation of intrinsic defect density seems does not act to modify the material flexural strength. Conversely, a considerable correlation between the induced defect density and flexural strength has been found.

Introduction

The presence of structural extended and point-like defects can impact SiC-based devices performances not only from the electrical but also from the mechanical point of view. Nowadays it is well known that SiC defects are detrimental to die electrical reliability and performance [1,2]; the impact they can have on device mechanical yield is not properly investigated. In this respect, an investigation on the correlation between defectivity, whether intrinsic or processing induced, and the mechanical strength of 4H-SiC substrate can be of use. The flexural strength, that is the stress the die can withstand under an applied load at breaking, has been used as reference parameter. Three point bending (3pb) tests have been exploited on well identified substrate regions and the collected data have been correlated with the corresponding defect density.

Experimental

Commercially available 150 mm 4H-SiC substrates have been used in this study. A set of substrates, characterized by different dislocation density (wafer #1 and wafer #2), have been used to study the effect of intrinsic SiC defectivity on mechanical strength. KOH wet etch process at 500 °C for 5 min has been performed to highlight the SiC crystal defects. Wafer surface optical inspection after KOH etching has been performed by automated optical microscopy (nSPEC by Nanotronics) to monitor the density and distribution of defects. Whole wafers have been inspected by using x10 objective. Another set of substrates have been used to study the effect of process induced defectivity on mechanical strength by performing thinning process and subsequently high temperature bulk thermal treatment and laser treatment at high fluence. Failure strength investigation has been performed on all wafers by 3 point bending test (Instron 5566) on a variety of 5x4 mm die properly selected per defect density along wafers. The tool accuracy is of 0.5% and the support span length is of 3 mm. Load has been applied in correspondence of the center of the span length and has been increased at a constant rate of 0.5 mm/min.

Results and Discussion

Commercially available 4H-SiC substrates with 4° off-angle and different defect density have been used in this experiment. After KOH wet etching [3] optical images have been collected all along the wafers size and the corresponding defect density map is shown in figure 1 a) and 1b) respectively for wafer#1 and wafer #2. Dots of different colors refers to different defect dimensions. The overall counting of 26621 defects have been detected for wafer #1 and 6251 defects have been counted for wafer #2. Beside the different defect counts, strong variation is also observed in defect distribution on wafer, marked with black and red circles respectively for high density (HD) and low density (LD) regions. Should be also underlined that different defect density among wafers is linked to the belonging ingot and the relative position within it as well as on growth conditions such as temperature, pressure and vapor equilibrium. To obtain statistically significant data, a total amount of 60 dies of 5x4 mm have been taken from each wafer from selected zones. The defect density calculated per each zone is reported in figure 2. In our wafers, based on the area under investigation, whether HD or LD, mainly BPD originated from stress caused by strain from lattice distortion [4] has been found and BPD arrays, half-loop array (HLA), have been found on HD zone.

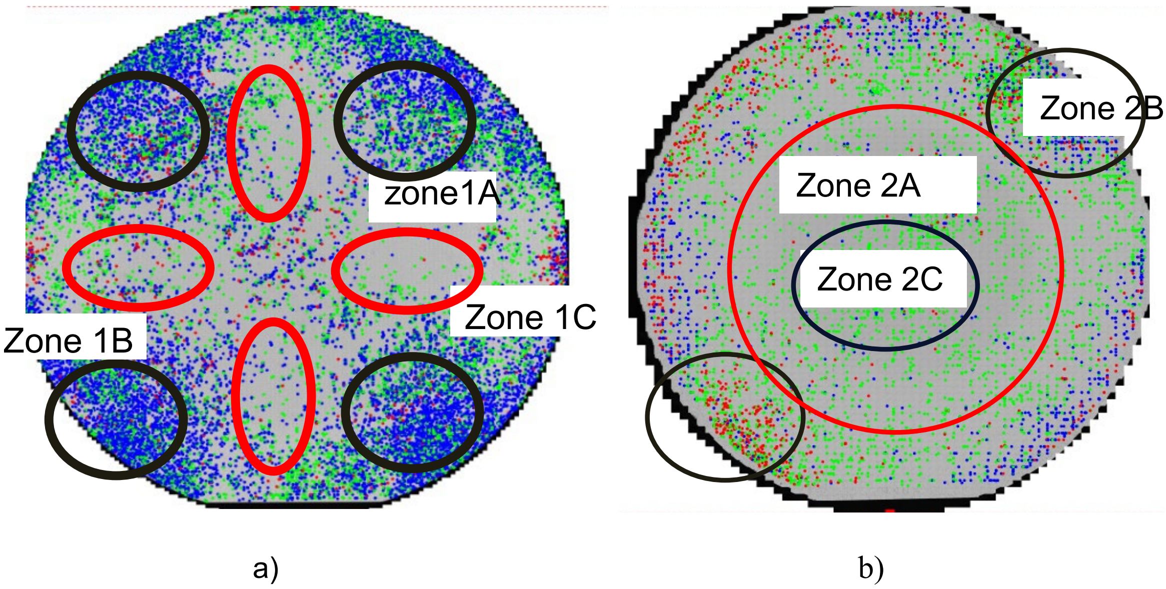

Figure 1. Wafer scale defect density distribution as obtained by n-spec analysis after KOH. etching for wafer #1 (a)) and wafer #2 (b).

Dies selected have been subjected to three-point bending test in order to calculate the stress σ the die can withstand at breakage (flexural strength)[5] that, based on the theory of a suspended beam of known geometry supported on both ends [6], it can be represented by:

$$\sigma = \frac{3FL}{2Wd^2} \qquad (1)$$

Where F is the maximum load, that is the load which causes die breakage and L,W and d respectively the length, width and thickness of the die. In our case the die dimensions are 5 x 4 mm and the die thickness is 350 um. Flexural strength values as calculated in correspondence of the dies selected from HD and LD regions on both wafers and compared with our finding in terms of defect density per each zone are shown in figure 3. On both wafers low flexural strength values have been found in correspondence of a defect density of about 500/die size, the flexural strength increasing by a factor of two if the defect density is higher than 600/die size and keeping almost constant on large range of defect density.

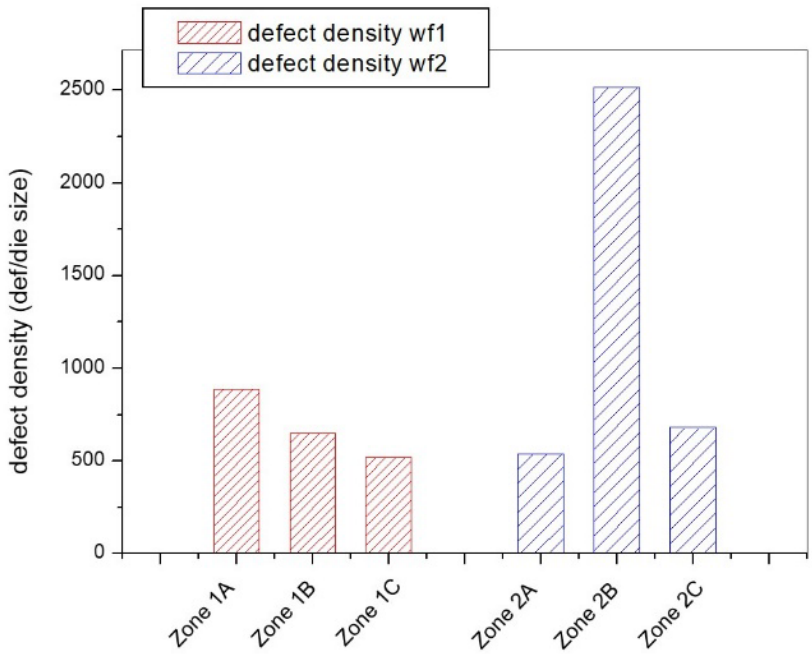

Figure 2. Defect density as a function of wafers zone per wafer#1 (red) and wafers #2 (blue).

No significant changes indeed have been observed for die strength in regions where defect density was up to 2000/ die size. It is to note that dies having low flexural strength in correspondence of low defect density represent 7% - 10% of total low density dies analyzed.

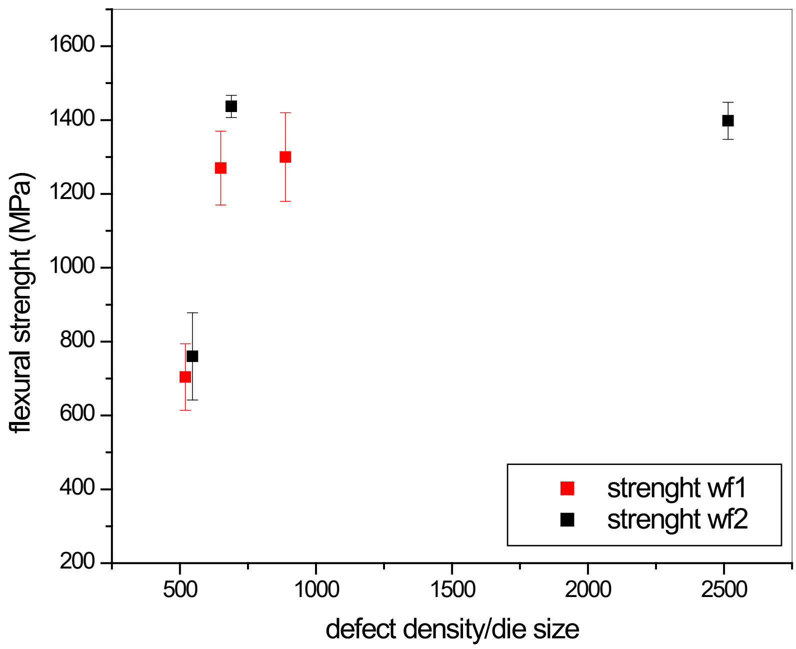

Figure 3. Variations of flexural strength as a function of defect density for intrinsic defects.

Apart from the intrinsic defects present in 4H-SiC crystal, during the device fabrication flow the SiC substrate undergoes to processes that can induce defectivity in the form of stacking fault, micro cracks and cracks. Sources of induced defectivity are the wafer thinning process, necessary for increasing device performances, reducing undesired power dissipation and providing greater package miniaturization, as well as the high temperature thermal treatments, whether bulk or local, necessary for example for dopant activation or silicide formation. Flexural strength data as a function of the above-mentioned processes are shown in figure 4 and compared with the corresponding values obtained for untreated SiC. The thinning process, a mechanically material removing process, causes a worsening of failure strength, which reduces from 1200 MPa to 800 MPa, across the wafers due subsurface damage in the form of microcracks and cracks introduced during the thinning. Failure strength values obtained for wafers subjected to bulk and laser thermal treatment after thinning keep almost unchanged with respect to the values obtained before thinning. With high temperature bulk annealing (>1700 C) the SiC crystal undergoes to morphological changes with 4° off terraces of multiple height steps and appearance of dislocation (here not shown) that contributes to keep low the failure strength. Finally, high fluence laser annealing, with high temperature gradient across the SiC surface introduces local compressive stress (estimated of the order of 100 MPa in our case) in confined region, surrounded by not thermally stressed region, that promotes further substrate damaging such as microcracks and hence possible mechanical break up.

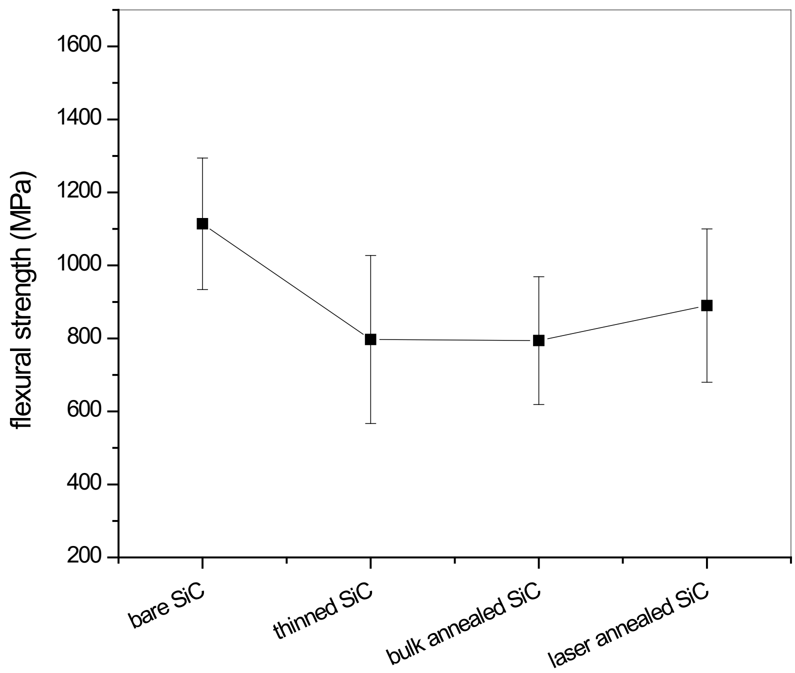

Figure 4. Variations of flexural strength as a function of defect density in case process induced defectivity.

This finding highlight that when we deal with alternative ways to the standard chemical mechanical polishing (CMP) and pure mechanical approach (dry polishing) to relief the stress induced by thinning and restore wafer surface, attention has to be devoted to the impact the process can have on the die mechanical strength.

Conclusions

The impact the intrinsic and induced defects can have on the mechanical strength of 4H-SiC wafer has been investigated by means of three point bending. It has been shown that the die flexural strength keeps almost unchanged on a large range of SiC crystal intrinsic defect density. As a difference, the defect density induced on SiC surface by thinning process reduces the die strength of a factor of 1.4, the value being almost unchanged in case of subsequent high temperature treatment.

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