Mechanical Characterization of Machining Results for Sintered Silicon-Carbide (SSiC)

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Abstract

Sintered Silicon Carbide (SSiC) is a hard and brittle material, preventing the ductile mode of machining and making it difficult to process. A promising technique for the cutting and profiling of SSiC in a good quality is ultra-precision dicing. Application of dicing for machining of SSiC showed that a high sidewall quality can be achieved. Thereby, two different areas could be distinguished on the diced sidewalls. One area is lighter and smooth, and the second area is darker and rough. In order to determine the origin of formation for these areas, a mechanical characterization of the diced sidewalls was executed. The results of these investigations are presented in this paper.

1 Introduction

The standard material for the fabrication of microsystems is Silicon or its Oxides. Mechanical processing of these materials is well-developed and well-understood [1]. If a higher mechanical resistance and strength for specific processes and applications is required, Si is not always the best choice. Due to its superior properties (hardness, toughness, thermal stability, and chemical resistance) SSiC represents a promising alternative. The machining of SSiC in a ductile or predominantly ductile mode is required to meet the high demands of form accuracy, surface quality, and low subsurface damage [2]. Ultra-precision dicing is a promising technique for achieving these goals. Preliminary tests showed that a high sidewall quality can be achieved by dicing of SSiC. Thereby, the feed rates between 0.1 mm/s and 0.5 mm/s were the most suitable for machining [3]. The quality of the diced profiles in SSiC was comparable to those made in Al_2O_3-TiC ceramic, although is SSiC coarse-grained and harder than Al_2O_3-TiC. Furthermore, the blade wear for the dicing of SSiC is lower than for the dicing of Al_2O_3-TiC. The reason for this behaviour should be better understood. Therefore, a detailed analysis of the machined sidewalls including the mechanical properties is conducted.

2 Experimental

For the SSiC machining, the dicing saw DAC 551 was used and the resin bonded dicing wheels were chosen. Due to its self-sharpening effect, a constant diamond grit exposure and constant cutting forces can be guaranteed. The dicing wheels had a thickness of 200 µm and the diamond grain size was 15 µm (marking 8-15H) and 30 µm (marking 8-30H), respectively. All the other parameters (feed rate and cutting speed, cutting depth, coolant supply) were kept constant. For machining tests, the rectangular substrates with a constant length of 25 mm and a thickness of 1 mm were used. The machining results were analyzed regarding the sidewall topography, kerf sidewall roughness, nanohardness and Young’s Modulus. The kerf profile and the sidewall areas were analyzed with a Confocal Laser Scanning Microscope (CLSM). A Hysitron TriboIndenter^{TM} system was used for the analysis of the mechanical properties of SSiC samples. The nanoindentation tests were executed with a three-sided diamond (pyramid-shaped) Berkovich tip. The system allows the measuring of the nanohardness and Young’s Modulus with indentation depths of a few 10 nm [4].

3 Results

3.1 Roughness of diced SSiC

The first analyzable property was the sidewall roughness. The topography of diced sidewalls was measured with CLSM and the roughness of the machined surfaces were determined (Fig. 1). All the diced sidewalls featured this same pattern.

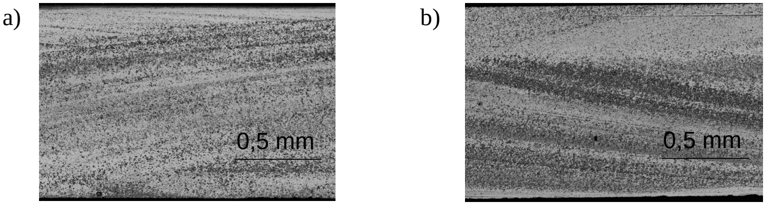


Figure 1: CLSM micrographs of diced SSiC sidewalls: a) with 8-15H and b) with 8-30H dicing blade

Basically, two types of surface areas could be distinguished: one area is light-colored featuring a low roughness (R_a <2 µm) and the other one is dark-colored with a considerably higher roughness (R_a >2 µm). Figure 2 depicts a difference in roughness (R_a and R_z) between the two sidewall areas for both blades.

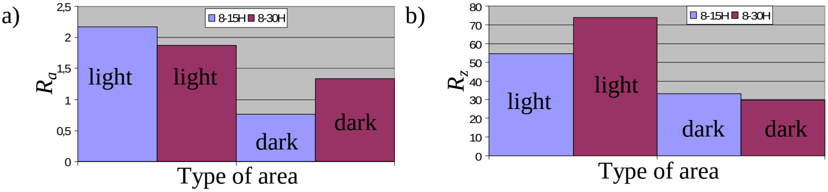


Figure 2: Roughness comparison of two blades: a) 8-15H and b) 8-30H

By dicing in different directions, alongside and across to the substrate, a potential material inhomogeneity was excluded. The similar surface patterns were detected on every sample independently of the machining direction.

3.2 Nanohardness and Young's Modulus of diced SSiC

In addition, the analysis of nanohardness and Young's Modulus for these two types of areas was done. Figure 3 depicts two selected micro areas, where the nanohardness was measured. The dicing grooves on the surface of the fine area are clearly visible. It features the marks of a predominantly ductile mode of machining. The nanohardness of the smooth (light) surface area is 41 GPa and for the rough (dark) surface area 25 GPa.

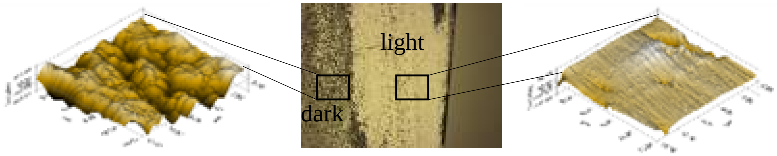
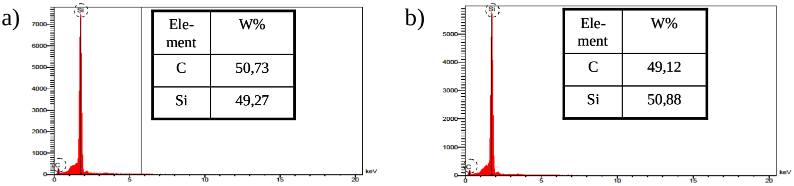


Figure 3: SPM picture of the different areas: dark (left) and light (right) area

The nanohardness measured on the unmachined surface of the SSiC was about 20-22 GPa (hardness of bulk SSiC in literature ≈ 30 GPa). The Young's Modulus of the light area amounts to 325 GPa and of the dark area approx. 291 GPa.

3.3 REM/EDX of diced SSIC

To eliminate a potential sample contamination by the binder material or material non-uniformity the sidewalls composition was investigated. Figure 4 depicts two material compositions of dark and light areas of SSiC sidewalls. The EDX analysis did not show any significant difference in the Si-C composition. The application of different cleaning procedures did not affect this composition. Therefore, the sidewall transition (brittle-to-ductile) can only be explained by machining conditions.



a)

Element	W%
C	50,73
Si	49,27

b)

Element	W%
C	49,12
Si	50,88

Figure 4: EDX analyses of: a) dark and b) light micro area

Figure 5 shows the transition from rough to the fine areas on the same sidewall. The dark area features a large number of porosities and indicates a predominantly brittle machining mode. The forming of dicing marks (grooves) on sidewalls refers to the predominantly ductile machining, especially on the light area.

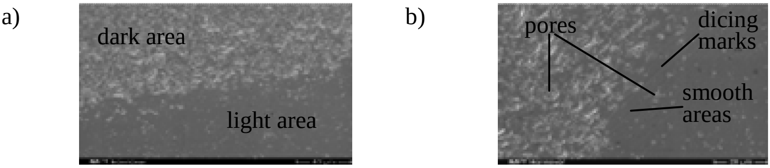


Figure 5: REM of SSiC sidewalls: a) 500 and b) 1,000 magnification

4. Conclusion

The machining results show that it is possible to machine SSiC in the predominantly ductile regime during standard dicing processes. The generation of two different surface areas can only be explained by machining conditions. A properly balancing of the machining parameter to utilize these effects can optimize the cut quality and enhance the predominantly ductile mode of machining. Further investigations are required to pinpoint the optimal parameter set-up supporting the ductile dicing areas and reduce it to practice.

References:

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