A Dicing study for highly productive micro production processes of porcelain-based ceramics for MEMS

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Abstract

Dicing still represents a main technology for separating or structuring hard and brittle materials. However, the high and frequent wear of machining tools (dicing blades) does not allow efficient machining. A new ceramic material and machining process are introduced to overcome this restriction. For this purpose, a porcelain-based ceramic is used. In its "green-state" (pre-sintered), it is well suitable for machining. Conducting the sintering process post-machining achieves extremely hard and tough surface properties, and introduces a low shrinkage. This paper presents a dicing study for highly productive micro production processes of porcelain ceramics for MEMS. Structures with an aspect ratio (<22:1) are achieved in green state with subsequent sintering with nearly no wear on the cutting tool.

1 Introduction

Due to the high hardness and brittleness of materials like silicon, silicon carbide, aluminium oxide and other ceramics, an ultra-precision grinding process is the most efficient process to guarantee a high surface and structure quality [1]. The conventional processing of ceramic materials like porcelain starts with a powder that is pre-sintered (green state), then machining to generate the desired form, and finishing the procedure with a subsequent sintering [2]. Due to their lower hardness, machining of green state ceramics allows high productivity and low tool wear. However, the strong ductile behaviour of green state ceramics leads to wall and edge deformations, as well as unavoidable shrinkage after the sintering process [3]. The green state of ceramics features lower hardness and lower shrinkage (~2%) after sintering, than the standard Low Temperature Cofired Ceramics LTCC (~15-20%) [4], which allows better machining and handling conditions with higher accuracy to shape. Conventional forming and sintering processes of ceramic powders do not necessarily give the high dimensional accuracy and the good surface quality required for functional and structural components [5]. In this work, the thresholds (max. aspect ratio, min. footprint) for the fabrication of microstructures on this type of green state ceramics are investigated. The change in mechanical properties (hardness, Young's-modulus) and structure shrinkage after the sintering process are determined. The results represent a foundation for establishing this type of material in MEMS technology in order to increase the efficiency of production.

2 Experimental

The green ceramics consist of an aluminium silicate based on pyrophyllite. The specimens prepared by a conventional milling process and then diced on an ultra-precision dicing machine DISCO DAC551 with a spindle diameter of 2 inch. For the tests, metal-bonded dicing blades with thickness of 100 µm and an outer diameter of 55 mm are used because of their high form accuracy. The dicing blades feature a grit size of 5 µm and 15 µm (4-5 NiF, 4-15 NiF; nickel binder with full diamond grit). The diced structures are investigated by measuring the profile using confocal laser scanning microscopy (CLSM) and a Hysitron TriboIndenter^{TM} system for the analysis of the mechanical properties.

3 Results

A dicing array is fabricated to identify the smallest structures to be machined. After a total cut line of 250 mm with a feed rate of 1 mm/s, no wear on the dicing blades can be noticed. The cutting groove depth is 480 µm and 600 µm for 4-5 NiF dicing blades and 4-15 NiF dicing blades.

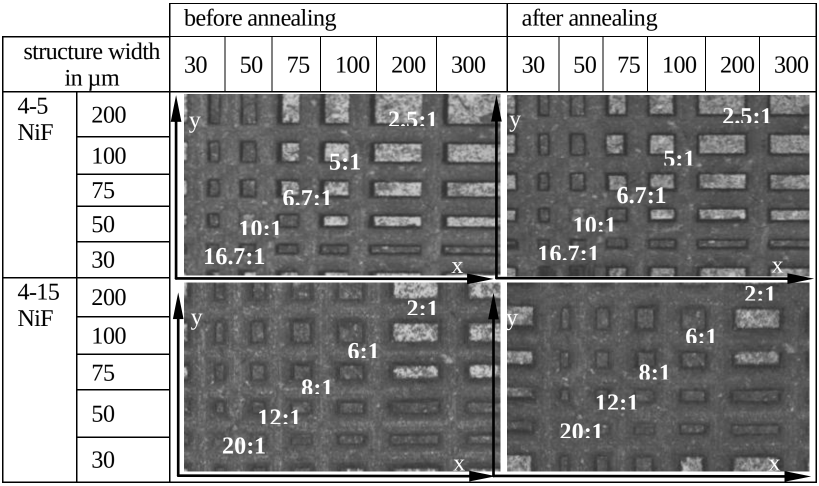

Figure 2: Dicing results for machined structures before and after annealing

The structures are measured before and after a gradually sintering up to 1.100 °C. Figure 2 shows the machined structures and the aspect ratio of the quadratic structures (cutting depth : structure length width). Using a 5 µm blade grit size, the lowest aspect ratio that can be achieved is 6.1:1. Using a 15 µm blade grit size, aspect ratios can be as low as 2:1. Rectangular structures are more stable than quadratic smaller plates, i.e. aspect ratios >2:1, and can therefore be machined by dicing.

The influence of shrinkage on the structure quality is shown in Tab. 1

Dicing blade		before annealing [µm]	after annealing [µm]
4-5 NiF	Height	477	485
4-15 NiF		608	621
4-5 NiF	R_a	2,7	2,9
	R_z	100	76
4-15 NiF	R_a	3,1	2,8
	R_z	62	76
4-5 NiF	x	116	114
	y	114	112
4-15 NiF	x	132	134
	y	129	126

Table 1: Geometrical results before and after sintering

It is observed that after sintering the structures increase in height (1-2%) and mostly shrink in the vertical and horizontal direction (1-2%). The surface roughness in the green state is high and strongly differs along the surface of the structure. In the sintered state, the surface roughness and roughness deviation decrease. The samples are unpolished to prevent deformation or structure cracks in green state. An average top face roughness (R_a) deviation of 2.8 µm and a mean roughness (R_z) of 76 µm is obtained. Small micro structures with an aspect ratio of 1:30 are achieved in green state ceramics.

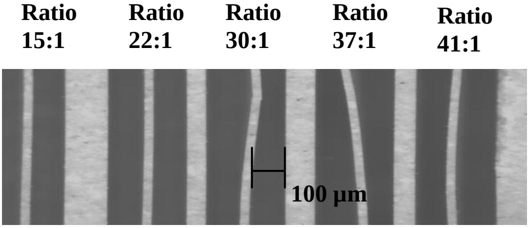

Figure 3: Deep dicing of green state ceramic (top face) after sintering

The thinnest walls have a thickness on the top face of 67 µm and at the bottom of the cutting groove 80 µm at a dicing depth of 2.800 µm. A strong warping of thin walls at aspect ratios larger than 22:1 (Fig. 3) is observed. For aspect ratios smaller than 22:1, thin walls maintain their initial shape. The warping effect is caused by the post-sintering shrinkage and increase in residual stress after binder loss and curing. The analysis of mechanical properties shows a five times increase in hardness due to the sintering process. Before sintering, the measured hardness fluctuates between 0.4 GPa and 1.5 GPa. After sintering, the hardness averages 7.0-9.0 GPa.

4 Conclusion and Outlook

The results show a high potential for high productive and low wear manufacturing of micro structures for MEMS, where high shape accuracy before and after sintering is achieved. Making use of the low mechanical hardness of green ceramics, manufacturing of complex microstructures before annealing is adopted. Structures with high aspect ratios, thin walls are produced by dicing green state porcelain ceramics. Future work encompasses the analysis of sintering processes and potential sinter phases in order to increase the aspect ratio of the machined structures, and reduce wall warping.

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