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Investigation for thinning-by-dicing of sintered and unsintered ceramics

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Abstract
Dicing of hard and brittle materials is still the main choice for machining the same. There are additional manufacturing processes for handling ceramics like silicon carbide, alumina or silica.
The mechanical machining of hard and brittle materials are mostly accompanied with induced cracks, chipping, tool wear, sub-surface damage, residual stress and influenced surface zones. These surface and sub-surface failures are adversely for later application of ceramics as a structural or functional part of MEMS. This paper shows a way to manufacture complex ceramic structures out of unsintered pyrophyllite without the negative effects of cracks, chipping and tool wear. High aspect ratios (35:1), thin ceramic carrier (35-50 µm) and nearly no tool wear can be connected with a more than sevenfold higher tool lifetime.

Dicing, ceramic, thinning-by-dicing, precision cutting, porcelain

1. Introduction

The green ceramic consists of an aluminium silicate based on pyrophyllite. It consists of 67% silica (SiO_2), 28-29% alumina (10-40 µm Particles), water, and small quantities of other minerals. Under these conditions, the low hardness, soft organic binder, low volume increase, high water content reduces the crack propagation and sub-surface damage. To reach the final material properties, a normal sinter process can be applied and the final structure is manufactured. After sintering the maximum volume increase is below 2%, for dried not sintered technical porcelain below 0.5%.

The grinding of brittle materials has been an intensely investigated field of micro production technology. Here are materials used such as silicon, glass and ceramics. There have been developed various methods, to process these materials efficiently with to a high quality [1, 2].

Demirci et al showed the main influence of the surface and sub-surface mechanism during grinding of silicon carbide. They showed a way to increase the productivity of machining advanced ceramics like silicon carbide [3]. Several studies showed that the introduced crack in the surface has a major influence on the achievable cutting quality. They argued that the tool and grit size has an impact on the nature of cracks spreading in the material [4, 5]. El-Wardany et al described a milling process for structuring unsintered silicon carbide parts. They concluded that a positive cutting angle induces cracks [6]. Jian-Zhong et al showed that the thermal treatment (drying, pre-sintering) increases the fracture strength of the unfired ceramic; however the wear of the tool increase as well. Here, however, it should be noted that the ceramic can shrink by up to 17% and thereby results in significant residual stresses in the ceramic body [7].

2. Experimental

The experiments were done on a precision dicing machining with metal bonded dicing wheels with a thickness of 100 µm and a grid size of 15 µm (4-15 NiF). The surface and structure measurements were done by confocal scanning microscopy and scanning electron microscope (SEM).

2.1. Thinning-by-dicing

The tests for thinning were to be realized with the construction in Figure 1. The advantage of this construction is that the fit between the carrier and the chip is the interface between both surfaces. These surfaces are planarized by lapping. In the grooves the joining material (Crytsalbond 509) is applied for fixation of the chip. Thus, the mounting permits a manual assembly accuracy of ≈5 microns. The release of this connection can be done thermally or chemically (acetone). In these experiments, the releasing by acetone was preferred because this leads to no additional deformation of the thinned chip. Thermal releasing causes warping and irregular peel of the chip.

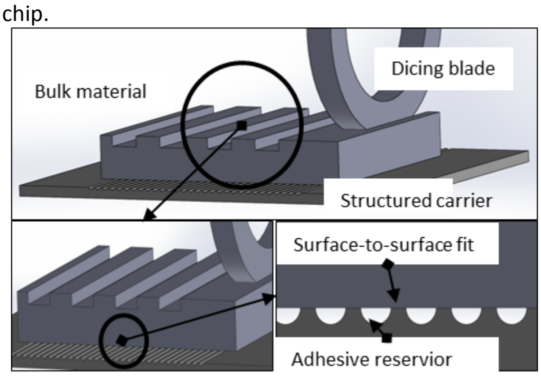

Figure 1. Thinning setup

Fig. 2 shows the dicing strategy, a structure is diced in the first step with respectively double dicing blade width. In the second step of rest of the material is removed.

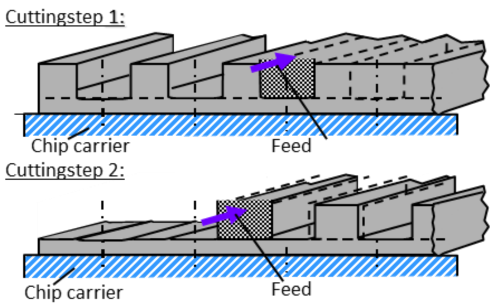

Figure 2. Dicing strategy for thinning [8]

This results in a uniform wear of the blade and prevents one-sided blade wear due to uneven contact conditions.

2.2. High aspect ratio structuring

The procedure for the structuring of the unfired ceramic was made in the same way as the thinning-by dicing. By knowing about the minimum thickness the maximum aspect ratio is produced with a wafer thickness of 2 mm. The challenge here is the handling of components and structures on the wafer level.

3. Results

3.1 Thinning-by-dicing

The thinning of sintered and not sintered ceramics show for sintered materials a critical thickness of 75-50 µm. Below this, the forces and the crack formation prevents thinner structures. Unsintered materials can be thinned down to 50-35 µm. Here no visible cracks are observed and the chip can be handled (Fig. 3).

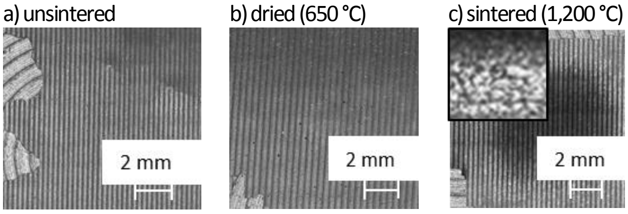

Figure 3. 35 µm thinned pyrophyllite

At this thickness, the handling and stability decreases. For sintered pyrophyllite (Fig. 3c) first visible cracks and handling problems occurs at this point. After sintering the unsintered and dried pyrophyllite, no visible cracks were noticed. The porosity of the pyrophyllite encourages the acetone-release and makes the handling of thin chips easier.

3.2 High aspect ratio structuring

Figure 4 shows the results after using the thinning process and the minimal thickness of the remaining material (50 µm). For this dicing setup the aspect ratio is 18:1 and can be increased by using thinner dicing blades up to 35:1. The apex angle α is <<1° and the chipping on the cutting edges is very low.

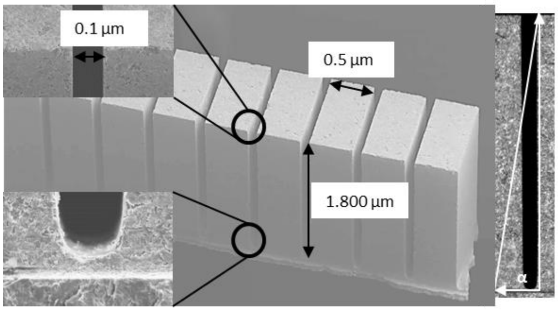

Figure 4. High aspect ratio in unsintered ceramics

For dicing these structures an array on wafer level was investigated. The challenge here is the handling after the structuring process (Fig. 5).

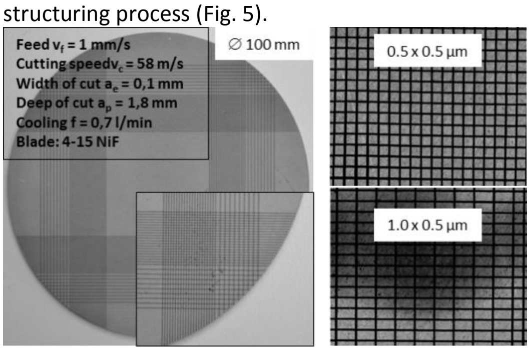

Figure 5. High aspect ratio dicing on wafer level

The used method from Figure 1 also works here. The wear ratio G_W is calculated to a ratio of the worked material volume (1.700 mm³) and the wear volume of the tool (0.25 mm³). For this long term dicing step the ratio is about 6.800 (compared to ceramic grinding of 500-1.000 [9]).

4. Concluding marks

Thinning-by-dicing was applied to sintered and unsintered ceramics. The unsintered ceramic pyrophyllite can machined easily, efficient with high cutting quality. They can be thinned with this process down to 35 µm with special mounting and handling steps. Before the sintering, there were no visible cracks in the unsintered material and the low shrinkage prevents a structural failure after sintering. The thickness limitation is accompanied by the particle size in the green state ceramic product (Al_2O_3 particles from 10-40 µm, inner porosity). Furthermore, the dried samples (650 °C drying temperature for 14 hours) seem to behave like rolled material. It curls up on the corner like rolled metal sheets. For thinning, unsintered material should be desired.

This work shows a way, how unsintered ceramics can be used in micro production for substrates, micro structures and passive elements. The limitations of grinding can be overcome, because this state of the ceramics can be structured by considerably more production processes. The knowledge about these brittle but soft materials is essential for failure analysis, long term stability, handling and integration into production of MEMS.

The next investigations expand the machining of unsintered and pre-sintered ceramics.

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