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Mass production for micro end mills

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Abstract

Micro end milling processes are not economical, as the tools are quickly worn out and their production is too cost-intensive. For this reason a batch-capable manufacturing process has been developed, enabling a simultaneous production of several thousand of silicon carbide (SiC) micro end milling tools. The manufacturing method is a combination of photolithographic structuring of a SiC-wafer and deep reactive ion etching (DRIE). The single tool heads with a height of more than 150 µm and a diameter below 30 µm are afterwards mechanically separated from the wafer and added on a shaft. Main points of this investigation are the performance of the optimized micro end mills, the tool geometry reliability and the milling surfaces quality. A systematic investigation by confocal scanning microscopy and scanning electron microscopy ensure a selection and characterisation of the precision geometry of the tools and micro milled structures.

Keywords: Mass production, batch process, silicon carbide, micro end mills

1. Introduction

The use of micro cutting processes such as micro end milling becomes an increasing issue in different fields of production technology. Micro end milling tools have to meet different requirements regarding their properties. In addition to the mechanical properties, the dimensional quality in terms of size and shape are important criteria. Furthermore the thermal shock resistance is an important characteristic [1]. The micro end mills are produced in a single unit production yet. After grinding, the micro end mills are usually coated, brushed or blasted singly to improve their performance. This implies high manufacturing costs and a low productivity [2]. For this reason, a batch-capable manufacturing process has been developed, enabling a simultaneous production of several thousand of silicon carbide (SiC) micro end milling tools [3]. The manufacturing method is a combination of photolithographic structuring of a SiC-wafer and dry etching by DRIE. Figure 1 shows the approach to batch production of micro end mills.

The single tool heads with a height of more than 150 µm and a diameter below 30 µm are afterwards mechanically separated from the wafer and added to a shaft. The feasibility of the manufacturing process was discussed in previous investigation [3]. Main points of this investigation are the performance of batch manufactured micro end mills, the tool geometry reliability and the surface quality after milling. A systematic investigation by confocal scanning microscopy and scanning electron microscopy ensures a characterisation of the manufactured tool geometry and the micro milled structures.

2. Experimental procedures

In previous publication [3], the desired wafer surface could be implemented and the developed process chain enables the production of functional SiC micro end mills. However some manufacturing failure of the tools, such as the inaccuracy of the structures, the coaxiality and planarity of the shaft and the end mill, were detected. These failures limit the tool life. Therefore current investigation will focus on alternative lithography masks, such as chromium mask. Further optimization approach is to integrate a die-bonder for precision die attach.

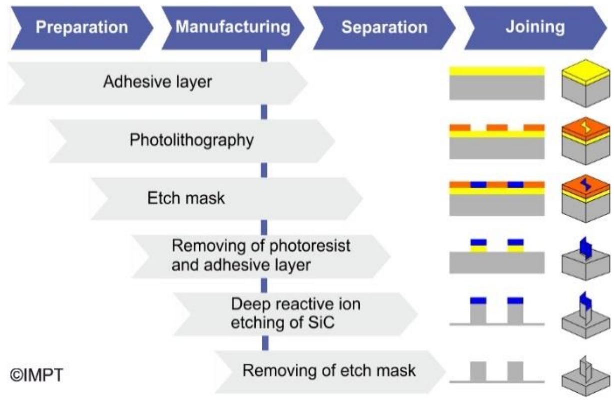

Figure 1 Batch production chain of SiC micro end milling tools

2.1 Optimized Batch production chain of SiC tools

A combination of coating, photolithography and electroplating is used to pattern the wafer with high etch resistance mask for DRIE. In case of nickel electroplating, a chromium adhesive layer (50 nm) and a nickel iron layer (100 nm) is sputtered on the SiC substrate. Inverse pattern of the tool geometry is created in a photoresist layer. A chromium mask is used to form patterns on the photoresist. This mask is produced using a laser beam pattern generator on a pixel basis, which makes it possible to define all kinds of shapes (smallest line width 1.5 µm). After an exposure process and development step the substrate is used for electroplating of nickel. Afterwards, the resist is stripped and DRIE is applied for the fabrication of SiC microstructures. Inductively coupled plasma etching (ICP180, Oxford Instruments) using sulfur hexafluoride (SF6) has been used to achieve high etch ratio and depths of 150 µm (height of milling head). In the next step, the micro end mills are diced into 1x1mm squares to prevent damages during separation and to simplify the handling during alignment and joining. Therefore a precision dicing machine is used to ensure that the dry etched micro end mill heads can be separated, followed by a sub-micron die-bonder (FINEPLACER lambda, finetech) with a placement accuracy of ± 0.5 µm, joining by bonding the tool heads with dual-component adhesive on aluminium shaft.

2.3 Experimental cutting investigations

The manufactured end mills shown in figure 2 have a diameter of 400 µm and a cutting edge radius of 3.2 µm. To study the influence of the optimized joining process on the tool performance, milling experiments of copper under various process parameters are carried out. The used milling machine is a 5-axis DATRON C5 with a spindle circularity of less than 1 µm. During the cutting operation oil is used as a lubricant. The depth of cut is kept constant at a_p=10 µm. The feed and the rotation speed of the spindle are varied in three steps (f = 13; 20; 27 µm at n = 30.000 and n = 30.000; 37.500; 45000 1/min at f=20 µm). For each of the six experiments a new tool is used. To evaluate the performance of the micro milling tools the tool life travel path L is taken into consideration. Therefore a feed travel of L = 1 m, which is comparable with conventional tools, is aimed during the experiments by machining 20 paths each with 50 mm length in the workpiece.

Burr formation is a major quality issue in micro milling of ductile materials. In order to evaluate it, the relative chip volume f_{ab} defined by *zum Gahr* is determined [4]. This measure represents the ratio of the chip volume relative to the groove volume. It is derived by dividing the area difference of uncut chip cross section (A) and piled-up material (A_1, A_2) by the uncut chip cross section (Figure 3):

$$f_{ab} = \frac{A - (A_1 + A_2)}{A}$$

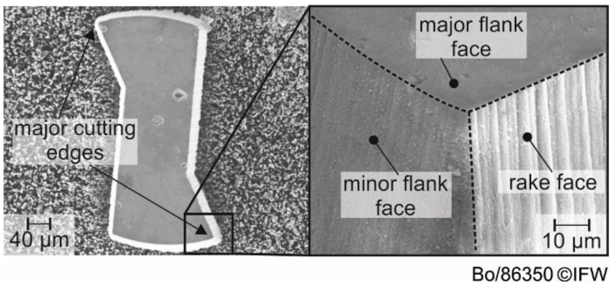

Figure 2 SEM Micrographs of SiC micro end mills

3. Results and discussion

All the investigated tools achieved the aimed feed travel of L=1 m, which is 500% higher than the tool life travel path before the optimization of the joining process. The measurements of all grooves widths W show an accordance with the diameter of the tools D, since the average and standard deviation are W = 402 µm and σ = 3 µm respectively. This substantiated the high coaxiality achieved by using the fine placer to join the milling head with the shaft. A high coaxiality means that both tool flutes are equally loaded during the milling process.

The comparison of the SEM-micrographs of two grooves manufactured by different rotation speeds in figure 3 show that the cutting process with higher rotation speeds leads to a higher burr formation. This is consistent with the relative chip volume f_{ab} since an augmentation of the rotation speed from n = 30.000 1/min up to n = 45.000 1/min, leads to a continuous decrease of f_{ab} from 0.97 ± 0.02 to 0.46 ± 0.21 (figure 4). For high rotational speeds a large part of the induced energy is converted into friction and consequently into heat. The heat build-up in the contact zone leads to a smear mode while cutting.

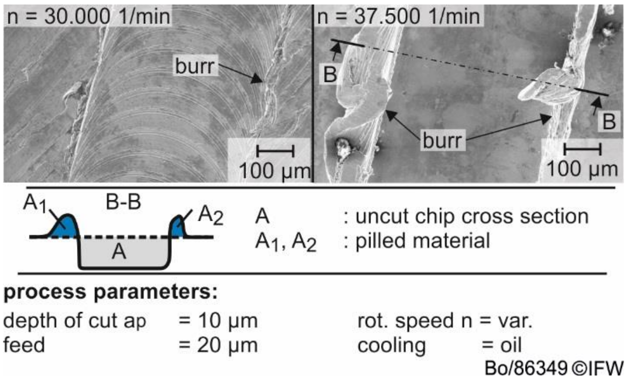

Figure 3 SEM Micrographs of milled grooves

The influence of the feed rate on the specific chip volume is lower than the influence of the rotation speed. By Increasing the feed from f = 13 µm to f = 27 µm the specific chip volume decreases from f_{ab} = 0.91 ± 0.04 to f_{ab} = 0.9 ± 0.02. A higher feed implies a higher chip thickness and consequently a higher mechanical load on the flute. Therefore material is displaced to the side of the groove without forming a chip.

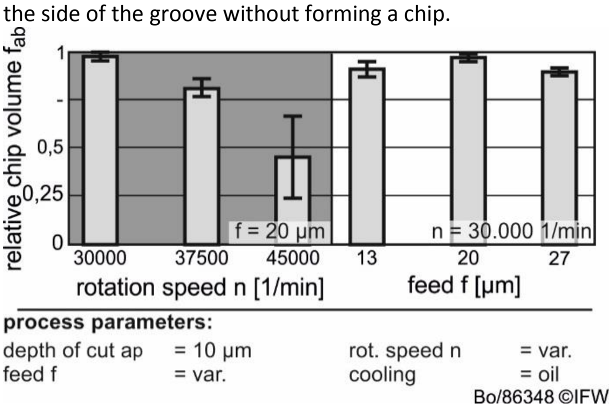

Figure 4 Cutting performance of SiC micro end mills

4. Conclusion

The presented work is an investigation of the in-process behaviour of batch fabricated SiC micro end mills. In order to improve the accuracy of the joining process during manufacturing and increase the coaxiality of the tools a fine placer was used. Due to this optimization it was possible to reach a higher feed travel compared to tools investigated before. Furthermore, investigations concerning the behaviour of the tools by varying the process parameters show the increase of burr formation at higher rotation speeds and feed rates. Future investigation will focus on tool life of the SiC micro end mills.

Acknowledgement

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