

Manufacturing of micro end mills by batch processing of silicon carbide

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Abstract

In the fields of micro system technology, medical engineering and biotechnology the use of components with filigree structures becomes an increasingly issue. The manufacturing of such components is realized by e.g. micro milling tools. The micro end mills have been produced individually and therefore incur higher manufacturing costs. The batch production is an approach to increase cost-efficiency of the micro milling processes by simultaneous manufacturing of several tools. In this paper a new manufacturing method of silicon carbide (SiC) micro end milling tools is presented and the performance is investigated. The experiments will show which aspects by the manufacturing process have to be considered to achieve a higher performance of the tools.

Keywords: batch process, dry etching, silicon carbide, micromachining, micro end milling tools

1. Introduction

By modern machining technologies, e.g. dry machining, high-speed or high-performance machining, cutting tools are subjected to high mechanical demands [1]. The development of new innovative processes requests suitable cutting tools. An adapted cutting material combines high hardness with fracture toughness and chemical stability. For the production of commercially available micro cutting tools wear resistant coatings with a tough substrate material are combined in order to merge the required characteristics. A total coating thickness between 3-10 μm is appropriate, where-by the combinations and sequences depend on the application. Especially in dry machining with coated tools, variations of the interface quality cause distinct differences in tool life.

Materials used in micro end mills have to meet a different set of requirements than those used in macro end mills. In addition the dimensional quality in terms of size and shape are fundamental criteria. For cutting applications thermal shock resistance is an important characteristic of adapted cutting materials [1]. The commercially available micro end mills are prepared by an additional production process after grinding to improve quality and tool life.

SiC substrates are used for manufacturing of e.g. biomedical micro devices or bearings. The material fulfils the needs of optical and tribological applications and it is also implemented in die and mold industry [2-4]. SiC has superior mechanical properties, i.e. chemical and wear resistance, high hardness and low thermal expansion and it can be used as micro end mills material for processing ductile materials, e.g. copper [5]. However there is a lack of experience of micromachining applications with SiC-micro tools. In this investigation, we report the SiC wafer processing combined with dry etching, dicing and joining technology for manufacturing of several hundreds of tools by batch process. Main points of the investigation, in addition to the production process, are the performance of micro milling processes in use and the process reliability. Systematic investigations ensure a selection and characterization of the defined shapes of the cutting edge geometry and micro milled profiles. The following sections

depict the production chain of SiC-micro end mills and their behaviour in use to achieve high performance by milling copper.

2. Experimental procedures

The process chain of manufacturing micro end mills by batch processing of SiC is comprised by the partial steps coating technology, photolithography of SiC-substrate, dry etching of the substrate by deep reactive ion-etching (DRIE) and joining technology. Fig. 1 shows the approach to batch production of micro end mills.

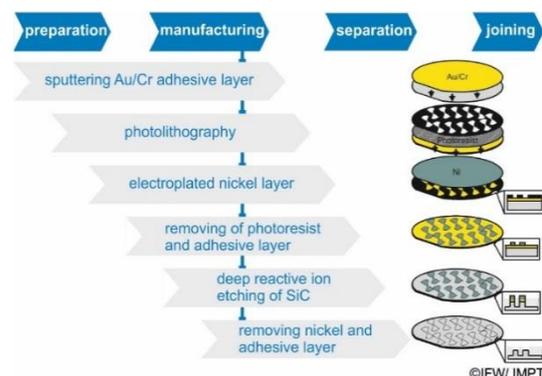


Figure 1. Batch production chain of SiC-end milling tools.

2.1 Preparations phase

The first steps are to define the layout of the tool geometry and to transfer the pattern of the layout to a photomask for the photolithography step. Surface preparation of SiC wafer (\varnothing of 100 mm, thickness of approx. 1mm) deals with a number of challenges in processing and in modification of surface treatment. The disadvantage of the commercially available samples is the roughness of the surface. This roughness provides a highly resistant surface region which withstands the cutting tool and workpiece interaction and affects its mechanical stability. One of the main requests in near-surface areas of cutting tools based on SiC is a high surface quality. Smoothness of the substrates is also required to apply thin film processes. In previous publication, the desired wafer surface qualities such

as high uniformity and low surface roughness are ensured by chemical mechanical polishing [6].

2.1 Fabrication process

To create a mask with high etch resistance for DRIE, a metal lift-off technique is used in combination with coating, photolithography, electroplating and etching to pattern the substrate with nickel. In case of nickel electroplating, a chromium adhesive layer (50nm) and a gold seed layer (100nm) is sputtered on the SiC substrate. Inverse pattern of the tool geometry (as well as nickel geometry) is created in a sacrificial layer (photoresist AZ9260), deposited by spin-coating. A foil mask is used to form patterns on the photoresist. After an exposure process, post-exposure bake and development step the substrate is used for electroplating of nickel. Afterwards, the resist is stripped and the adhesive and seed layer is etched by ion beam etching. Within next step, DRIE is applied for the fabrication SiC microstructures. Inductively coupled plasma etching (ICP180, Oxford Instruments) using sulfur hexafluoride (SF_6) has been used to achieve high aspect ratio structures to depths of 150 μm (height of milling head). A modified process is adopted, which alternates etching with conformal deposition of an etch-inhibiting polymer and cooling phase. 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 und joining. Therefore a precision dicing machine is used to ensure that the dry etched micro end mill heads can be separated, followed by optimal alignment with a microscope, joining by bonding the tool heads with a metal shaft and as required post processing.

3. Results and discussion

3.1 Characterization of the end mills

While using the described end mill manufacturing method geometric failures occur during DRIE-process, while separating the structures from the wafer and while putting the end mill structures together with the shaft (see Fig. 2). The manufactured geometries show higher cutting edge radii. This inaccuracy is due to the used foil mask. While separating the end mill structures from the SiC-Wafer a geometric deviation consisting of a coaxial shift between the middle of the quadratic body and the structure (K_1) is detected. This deviation is $K_1 = 1 - 5 \mu\text{m}$. The end mill structure and the shaft have an adhesive bond. While applying the adhesive layer, two kinds of failure can occur. On the one hand the thickness of the layer could vary. Therefore a flatness failure between the end mill and the shaft (P) occurs. On the other hand a positioning inaccuracy occurs with a coaxiality failure between the quadratic body and the shaft K_2 .

For this investigation 32 micro end mills were manufactured according to the described method. To evaluate those tools the total coaxiality K_t , which could be measured between the end mills structure and the shaft, and the planarity P will be considered. The total coaxiality ranges between 16 μm and 260 μm and the flatness is between 6 μm and 116 μm . For the experimental micro milling investigations the inaccuracy of the structures due to the DRIE-process will not be considered, since all the end mills have the same cutting edge radii.

3.2 Experimental investigations

The applied tools have a diameter of $D = 300 \mu\text{m}$. To investigate the influence of the detected failures the tools are divided in two groups. The first group consists of tool-pairs with variable coaxiality and constant flatness. The second group includes tool pairs with variable flatness but constant coaxiality.

kind of failure	rounded cutting edge	coaxiality K_1	total coaxiality K_t	planarity P
results	40 μm - 60 μm	1 μm - 5 μm	32 μm - 200 μm	6 μm - 100 μm

tools: SiC micro milling tools; measurement method: digital microscope
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Figure 2. Manufacturing failures.

Fig. 3 shows the tool life travel path L in dependence of flatness and coaxiality. For tools with high coaxiality or flatness a lower feed travel is detected. Tools with a coaxiality of less than 100 μm and at the same time a flatness of less than 40 μm reach a feed travel of $L = 1 \text{ m}$, which is comparable with usual micro milling tools. Furthermore untypical cutting edge chipping were detected at the tools with coaxiality and flatness failure upon 100 μm and 40 μm respectively, since the manufacturing failures leads to different mechanical loads of the cutting edges. Furthermore the geometry of the tools prevents the transport of the chips so that they are jammed in the contact zone. This leads to high passive forces which caused the cutting edge chipping.

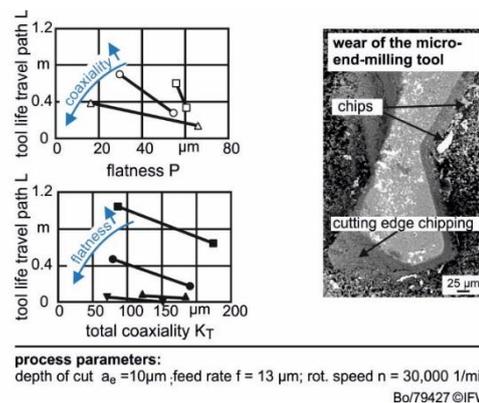


Figure 3. Influence of manufacturing failures on the tool life travel path.

4. Conclusion

The investigation shows that 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 and future investigation will focus on alternative lithography masks, such as chromium mask and laser direct imaging. Further optimization approach is to integrate a die-bonder for precision die attach in combination with thermo-compression providing mechanical strength and stability.

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