New micro diamond milling tools

J. P. Wulfsberg, G. Brudek, J. Lehmann
Helmut-Schmidt-University/University of the Federal Armed Forces Hamburg, Laboratory of Production Engineering, Holstenhofweg 85, D-22043 Hamburg, Germany.
Jens.Wulfsberg@hsuhh.de, Gregor.Brudek@hsuhh.de, Joerg.Lehmann@hsuhh.de.

Abstract
The increasing requirements regarding form and surface qualitiy of cutting tools used in micromanufacturing increasingly become difficult to fulfill with conventional manufacturing processes. Alternative methods, for example Ion Beam Machining or Chemical Vapor Deposition (CVD) based procedures, could offer advantages, for they do not only make smallest dimensions possible, but in addition allow the desired manufacturing tolerances of the tools to be met. As an example of a diamond growth process the development and testing of diamond side milling cutters for application in microtechnology are described.

Introduction
Electronic, mechanical, optical or fluid-based miniaturized systems are increasingly used in biotechnology, medical technology, sensor technology or in mechanical engineering and vehicle construction, too. Here on the one hand a miniaturisation of the components is demanded, on the other hand a gain of functionality is desired. Both can be reached by a combination of methods for microelectronics or microsystem engineering and scaled procedures of precision mechanics. A limitation of scalability is reached today in manufacturing of scaled tools for forming and, as outlined in this contribution, for cutting procecces. Normally grinding will be used to manufacture the final geometry of the tools, but these methodes are influenced by miniaturization. The ongoing miniaturization of micro tools is disabled by these effects. Today one possible way is to use material removing methodes with a high precison and resolution, like electrical discharge machining or ion beam machining. A further alternative could be represented by generative methods, where the geometry is created by material growth. These include the different CVD-processes, e.g. plasma-enhanced CVD-process, which are supported by external energy. The much higher pricison and resolution of these processes should be used for the production of full-diamond micromilling tools. [1,2,3,4]

Technology
Because the CVD processes available today are coating processes, first the development and the production of 2½ dimensional discoidal tools were accomplished. For this purpose side milling cutters with a diameter of 2 mm and thickness of 30 µm were designed and made available as CAD files. The number of teeth were varied between 4 and 10. In this first attempt clearance angle and chip angle were specified following the geometry of macrotools (fig.1). The CAD data was used by the project partner GFD (Gesellschaft für Diamantprodukte GmbH, Ulm, Germany) for the production of a mask in which 12 milling tool types with different cutting edge geometries were represented. In the CVD process the material (in this case diamond) passing through this mask is deposited on a silicon substrate. The lateral geometry of the tool is thus spezified by the mask, while the width (thickness) of the cutting tools is determined by the process time and can be controlled with high resolution. [5]

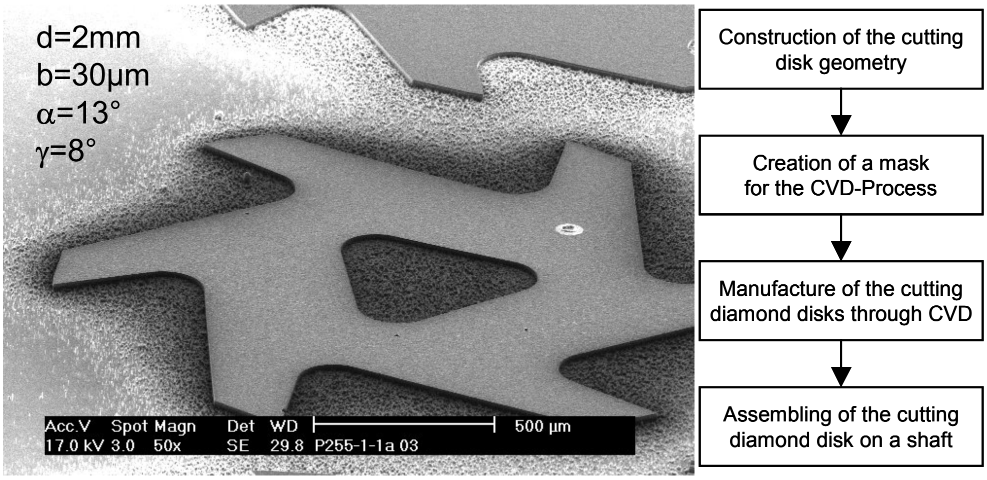

Fig. 1: *Side milling cutter manufactured by CVD based procedures*

During the CVD process polycrystallins diamond layers of highest density are deposited from a gaseous phase (hydrogen-methane gas mixture) by the addition of high energies. With this method layers with a size of approximately 15 cm (6 inch) in diameter can be produced on the silicon wafer. GFD uses thereby different CVD procedures, which are selected as a function of the layer quality and the substrate to be coated. One of these procedures is PECVD (Plasma Enhanced Chemical Vapor Deposition), where a good layer growth is possible despite the low process temperature. At the end of the growth process, the cutters are isolated by removing the silicon substrate through an etching method well known from microelectronics. **[6,7,8]**

Finally the side milling cutters are assembled on a shaft via a gluing process. Figure 1 shows a diamond side milling cutter produced by a CVD-process and clarifies the flow of the manufacture processes. Figure 2 shows an assembled cutter.

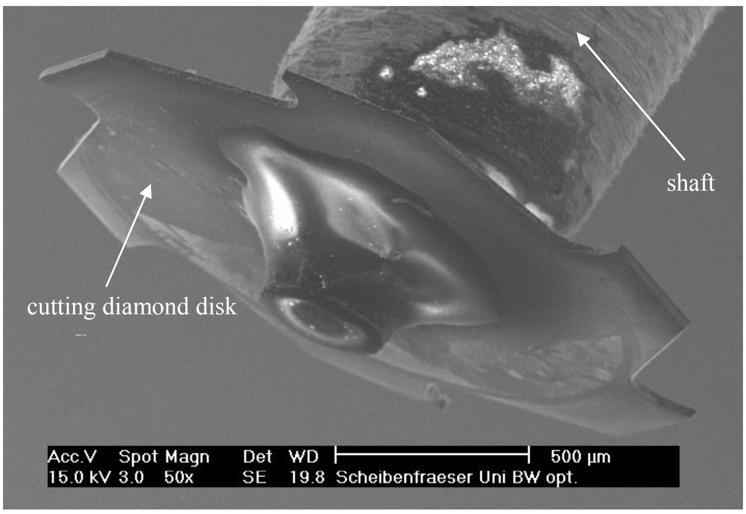

Fig. 2:: *Installed diamond micro side milling cutter*

Experiment

At the LaFT (Laboratory of Production Engineering of the Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg) the first prototypes of the diamond side milling cutters were tested in a Kugler micromachining center. It fulfils the special requirements of microproduction: air-stored linear axes, a measuring system with a resolution of 10 nm and a positioning accuracy of 0,3 µm as well as a high frequency spindle with a maximum speed of 160000 revolutions per minute.

For the experimental investigations the aluminium alloy Al Mg 3 and brass Cu Zn 37 were used as steel and ferrous metals are difficult to machine with diamond tools because of their chemical affinity for carbon. The goal was the production of slots with an high aspect ratio, i.e. a high depth compared to the width of the slot. The cutting parameters selected were: speed n = 160000 min^{-1}, feed rate v_f = 10 m/min and an infeed of a_e = 0,025 mm. Figure 3 shows the geometry of the produced slots.

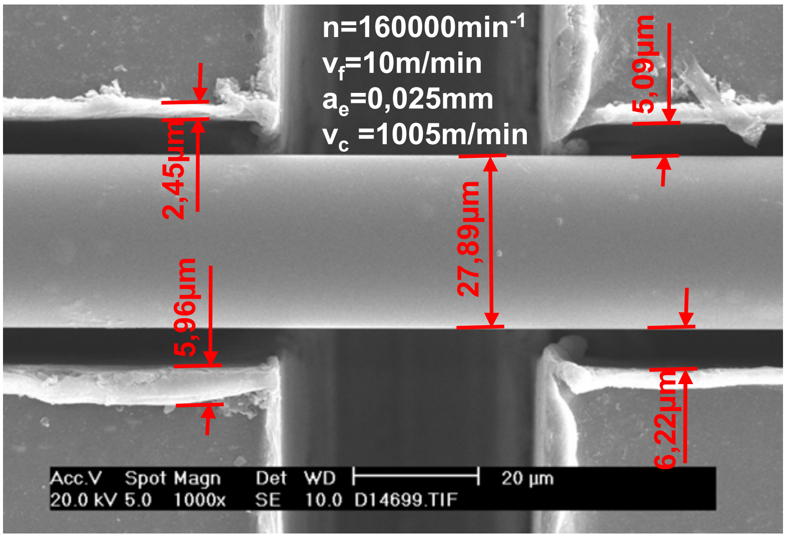

Fig. 3: *With diamond micro side milling cutter produced groove with inserted optical fiber*

Conclusions

In the experimental investigations carried out, mainly the general suitability of the multicristalline full diamond-tools produced by the CVD-process should be reviewed. After a milling length of 1250 mm no outbreaks could be observed at the side milling cutters, showing that the tool life travel or the tool life end was not yet reached. Wear measurement could not accomplished so far as the usual measuring procedures were not applicable to the miniaturized tools. However the suitability of the developed tools for microcutting operations could be proven. Systematic parameter studies in the future will clarify the area of application of the micro side milling cutters.

Due to their geometry the side milling cutters seem specially suitable for the production of parts with slots with high aspects ratios, e.g. in the field of microoptics, microfluidic systems or the micromechanics. The part produced (figure 3) shows an example of microoptics with an optical fiber with a diameter of 30 µm guided in the milled groove. Such channel structures can be used likewise in microreactors or in micro heat exchangers.

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