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Electroless plating and application of micro pencil grinding tools with a diameter of ~5 µm

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Abstract

With constant improvements in micro-machining processes like micro grinding with micro pencil grinding tools, micro structured components such as micro electrophoresis chips or micro fluidic mixers are continuously decreasing in size and weight all while maintaining a decent surface quality and accuracy. Micro grinding processes in general offer a flexible small batch production process with high geometrical flexibility. Micro structures with almost arbitrary cross-sections are possible. The dimensions and the shape of the cross-section depend on the shape and size of the MPGT tool tip. In order to achieve smaller structure sizes, precise machine tools as well as a precise coating method are required. This paper presents a tool grinding method to manufacture the geometry of a micro pencil grinding tool substrate down to a diameter of 2-3 µm. Combined with an electroless plating process, tool diameters of ~5 µm with a grit size of 0.5-1 µm are achieved. In addition, a machined structure is presented to validate their functionality.

Micro pencil grinding tools, micro machining, electroless plating

1. Introduction

The motivation for the fabrication of smaller workpieces was essentially the same since manufacturing technology established itself as a science. The demand for increasingly smaller components runs paralleled with the improvements in micro machining [1]. Among the mechanical processes, micro grinding with micro pencil grinding tools (MPGTs) has a prominent advantage over other machining processes as it is applicable for hard and brittle materials like silicon, glass, ceramics and cemented carbide [2]. Such materials are needed for applications in mechanical-electrical, medical and biochemical devices [3].

In this paper, MPGTs with a diameter of ~5 µm are manufactured using an electroless plating method. This marks the first time in which both the manufacturing and application method are presented for MPGTs with this size. The micro tools are then used to machine grooves in hardened 16MnCr5 workpieces. Both, the MPGT manufacturing parameters as well as the machining parameters are presented.

2. MPGT manufacturing process

High-speed steel was used as substrate material. The substrates tips were machined applying thin grinding wheels [3] to a final diameter of 2-3 µm and at a length of 250 µm. This high aspect ratio was caused by the grinding wheel used to manufacture them. Due to its large radius, only a small portion of the substrate can have the desired cylindrical shape (see Fig. 1 a) and e)).

Electroless plating is an autocatalytic reduction process. It uses a phosphorous reducing agent to provide an active substrate with the electrons necessary to reduce Ni^{+2} nickel ions found in the plating solution to Ni^{+0}, thus producing a phosphorous nickel layer. Once the solution reaches its pH value of 5.2-5.4 and its operating temperature of 87 °C, the only parameter influencing the nickel layer thickness is time. This can be utilized to calculate the layer thickness and the protrusion of grits added to the plating solution [4]. The components added to the solution are presented in Fig. 1 b). Fig 1 c) shows the schematic of the beaker with the plating solution and the abrasive grits. Fig. 1 d) shows the schematic of the finished product. The final product can be seen in Fig. 1 f). For larger tools, manufacturing residues and lose grits are removed via cleaning clay. However, for tools ~5 µm, using cleaning clay would bend the tool tip.

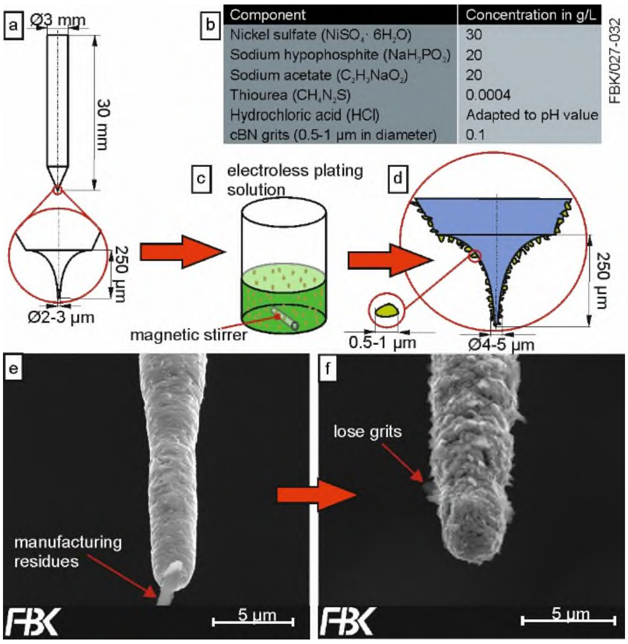

Figure 1. MPGT manufacturing process

3. Machining experiment

A precision 4-axes machine tool (Fig.Figure ***2*** a) was used for the application of the MPGTs. This machine tool is built up on a massive granite bed with a moving table design. The tables provide an air bearing system and are powered by stepper motors and ball screws at a resolution of 2.54 nm in X- and Y-axis. The Z-axis is guided by a cross roller and is also powered by a stepper motor and a ball screw. All axes have a maximum travel of 100 mm and a positioning accuracy of < 1 µm. The rotational axis A for setting the spindle inclination as well as the spindle are mounted on top of the Z-axis. The spindle has a manually adjustable clamping system to reduce reclamping errors to a minimum; a feature necessary for electroless plated tools as the coating is done outside of the machine tool and the tools hence cannot be manufactured and applied without reclamping.

A rotational speed of 30,000 rpm was applied for the experiments. This rotational speed resulted in very low cutting speeds. However, it was observed that MPGTs used with this rotational speed have a higher tool life than those used with higher rotational speeds [3]. Run-out errors of < 3.5 µm were measured at this rotational speed, a run-out error common with commercially available spindles.

A suitable depth of cut of 2 µm was applied for the process. The Z-axis is zeroed before the process by moving the tool towards the workpiece to scratch the surface. The scratching process is done manually by the machine tool user. It is conducted by moving the tool until chip removal is seen in the camera. This difficult process inevitably results into an error, estimated as 1 µm in Z-axis direction.

A number of experiments were conducted to determine a feed rate suitable for the process. The feed rates applied ranged from a feed rate of 1 µm/min up to 160 µm/min. Feed rates below 10 µm/min were not able to reach a chip thickness that allows for material removal to happen, while feed rates below 20 µm/min showed a tool life that produced grooves that are only few tool diameters in length. A feed rate of > 100 µm/min resulted in a short tool life as well. Hence, a feed rate of 50 µm/min was used to machine the structure featured in Fig Figure ***2*** c and d.

A metal working fluid (MWF) made of a mixture of distilled water and the solid lubricant sodium dodecyl sulfate (SDS) was applied. A flood supply of MWF is generally not suitable for micro machining as a high flow pressure of liquids may influence the tool behavior by applying an additional force [1]. Hence, a conventional minimum quantity lubrication (MQL) system was used [3]. Small quantities of < 100 ml/h were applied to the process.

The structure in Fig Figure ***2*** c and d had a length of 497 µm at a roughness value R_a of 12.5 nm, determined using confocal microscopy. As seen in Fig Figure ***2*** d, the structure was heavily influenced by the original surface topology of the workpiece. A more precise workpiece preparation method is required – an MPGT with a diameter of 50 µm will be used for this task in future works. The structure depth was measured to 450 nm. This value shows inaccuracies resulting from the machine tool, the workpiece and the scratching process as well as tool wear.

4. Conclusions and outlook

A method to manufacture and use micro pencil grinding tools with a diameter of ~5 µm was tested in this paper. Using thin grinding wheels, substrate diameters of 2-3 µm could be achieved. An electroless plating process was used to gain an abrasive layer with a grit size of 0.5-1 µm.

A rotational speed of 30,000 rpm, a feed rate of 50 µm/min and a cutting depth of 3 µm proved to be suitable parameters to conduct micro grinding experiments with the given tool specifications. A groove length of 500 µm was achieved at a roughness value R_a of 12.5 nm.

While both the manufacturing and the application method proved to be a success, the machine tool setup has to be modified to improve the process. The most important modifications would be to apply spindles with a lower run out, to better prepare the workpieces (smoother initial surface topography) and to achieve a more accurate scratching process.

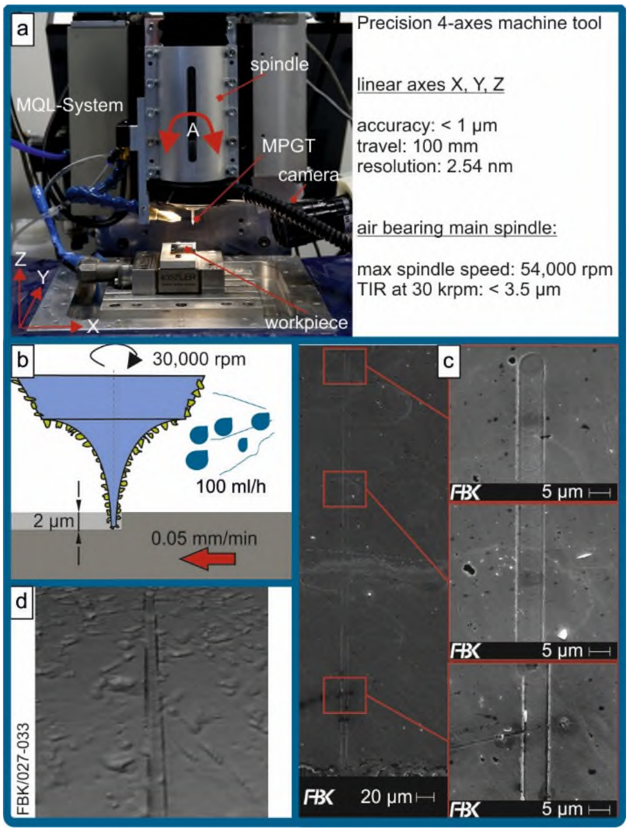

Figure 2. a) Precision 4-axes machine tool [3] b) micro grinding schematic, c) SEM image of micro structure and d) confocal microscopic image of micro structure

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