High precision laser structuring of micro forming tools

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Abstract

Because of the increasing demands for cost-effective and high-precision micro fluidic components the micro hot embossing technology becomes more and more important. An essential element of this technology is the required micro forming tool. At the moment the requirements for the minimum tool sizes are in a range of 100 µm with accuracy below ± 2 µm. However, the exactness demands partially can reach to the sub micrometer area [1].

The required structural sizes and structure forms as well as the used tool materials limit the application of conventional processes like milling. The structuring with laser offers an alternative method because the material removal with a laser beam allows the manufacturing of very fine structures also in hard and brittle materials. For initial experimental investigations a high strength ceramic material (silicon carbide) was used to produce forming tools for micro fluid components. It succeeded to produce structures with dimensions smaller than 20 µm and in a depth of 200 µm. The evaluation showed very good surface qualities (roughness below R_Z 2.55 µm) and a high geometrical accuracy. First replication experiments in PMMA (polymethyl methacrylate) and polycarbonate also show good results and comparable structure qualities.

1 Introduction

The field of micro fluidics and especially the micro hot embossing of such structures becomes more and more important. The needed micro forming tools have to be adapted accordingly to fulfil the geometrical demands for these micro structures. For inserting fine geometrical structures in high-strength materials the laser ablation can be used. Micro sized structures with minimum corner radius can be generated by very small spot sizes in a few micrometers.

A difficulty of the laser treatment is the complex influence interaction on the material removal rate by variable process parameters like laser power rate, pulse frequency and pulse overlap, these are determine the geometrical accuracy of the achieved structures. Therefore, it is necessary to carry out systematic investigations to determine the influence of the single process parameters on the material removal, in order to guarantee the process stability.

2 Experimental setup for laser structuring

A laser processing machine with a frequency doubled Nd:YAG laser (wavelength 532 nm), is operated at Fraunhofer IWU in Chemnitz. The laser beam focusing is realized by a scanner unit with a telecentric f-theta lens, whereby a focus diameter of approx. 9 µm on a working field of 40 x 40 mm² can be achieved.

For the supervision of the removal process and the adjustment of the focus position a "Keyence" laser distance sensor is used, whereby it is possible to control the machining level before and after the treatment. Using this, the removal levels can be held steady to generate defined geometry heights and forms. Two cameras for process monitoring and position measuring also allow controlling the ablation process and the alignment of the micro structures. Within the working area the laser beam is guided on the material surface by the laser scanner unit. To achieve high aspect ratios and small side wall angels the laser beam have to be aligned vertical to the work piece surface. This is enabled by using a telecentric f-theta lens.

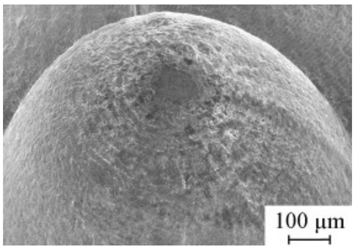

Figure 1: 3D-structure in SiC

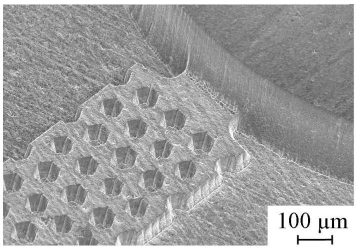

Figure 2: Fluid structure in SiC

Besides, material is removed selectively by controlling the laser energy according to the work piece geometry. The required laser tracks for structuring can be described by single lines, which allow a plane material removal. Complex geometries can be described by 2D CAD line figures. Through the selective variation of the single manufacturing layers also complex 2½D geometries can be manufactured e. g., special fluidic components (see fig. 1 and 2).

3 Micro laser structuring for forming tools

The machining results are dependent on the mechanical and physical parameters of material as well as the process parameters like laser power rate, pulse frequency and process atmosphere. Through the systematic investigation of the influences of single laser parameters on the removal process, useable manufacturing parameters for different materials could be determined.

For the hot embossing of micro fluidic components in polycarbonate and PMMA, silicon carbide is used as a typical tool material. This material was selected because of its high firmness and of its very good machining properties by means of laser. For the required micro fluidic components a negative mold with dimensions below 50 µm and depths between 50 and 200 µm was manufactured. The edges and the ground of the structure should have a high surface quality, especially with respect to following forming processes. High surface roughness could be led to unwanted demoulding forces during the embossing process.

For better side wall qualities, a special manufacturing step by laser was applied. Using this manufacturing technology, side wall angels of approximately 5 degrees can be achieved. This is optimal for the demoulding of embossed parts. At the same time the roughness of the side walls can be improved.

4 Conclusions

By means of the direct laser structuring a defined removal of material is possible and microstructures with dimensions of few micrometers and with good surface qualities can be produced in hard and brittle materials.

By using aligned laser and scanning parameters it is possible to achieve determined removal rates and a high geometrical accuracy. For the generation of micro fluidic structures in plastic materials a silicon carbide embossing die (see fig. 3) was manufactured. The embossing of the generated structures in polycarbonate and PMMA has shown that very fine structures below 20 µm (see fig. 4) with high aspect ratios of 4 can be replicated.

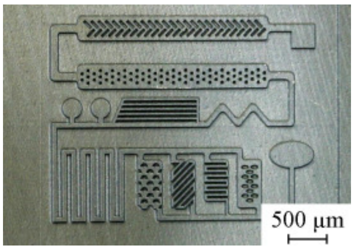

Figure 3: Fluid forming tool in SiC

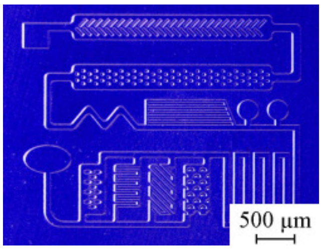

Figure 4: Formed in polycarbonate

The laser structuring process enables a convenient and rapid adaption for testing and evaluating of several structure elements. First verifications of the complete process chain have appeared very good results concerning the accuracy and the usability of the generated micro fluidic components.

The intended application of these micro fluidic structures should be a novel micro fluidics based test strip for fast point and home care measuring of glycated haemoglobin (HbA1c). This is an essential goal of the German joint project "HBA1C-SENS", which is supported by the German Federal Ministry of Education and Research (BMBF).

References:

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