Manufacturing of micro fluidic moulds by combining micro milling and laser structuring

A. Schubert, S. Gross, U. Eckert, J. Edelmann
Fraunhofer Institute for Machine Tools and Forming Technology IWU, Germany
stefan.gross@iwu.fraunhofer.de

Keywords: laser machining, micro milling, micro fluidics, micro manufacturing, combined processes

Abstract

Increasing demands regarding the functionality and the functional density of micro fluidic systems require constant miniaturisation of single components and also of the complete system. A cost efficient and effective manufacturing process requires replication processes such as injection moulding or hot embossing to structure disposables cost-effectively. This paper presents the development of the sequential process combination of laser micro structuring and micro milling for the manufacturing of micro fluidic moulds.

1. Motivation

Fast and cost-effective diagnostics of clinical values enables better and more effective treatment of diseases, especially in the field of home care. In this context lab-on-a-chip systems offer an interesting approach compared to complex and cost-intensive diagnostic systems or laboratory diagnostics. In addition to the actual analysis, micro fluidics plays a decisive role in such systems. Replication of these fluidic systems and generating defined micro structures puts high demands on the utilised manufacturing processes. Hot embossing enables fast and economic replication of micro fluidic elements with the requested structural sizes. In hot embossing processes, a master structure on a mould surface is pressed into a substrate at elevated temperatures, forming a negative relief replica of the master topography [1].

The required moulds have to achieve special demands regarding the surface quality and the accuracy of the micro structures, which requires established manufacturing processes to reach their limits. To resolve these limits on the one hand new production technologies such as laser ablation or electro-chemical manufacturing can be used. On the other hand the combination of new and established production technologies brings an interesting starting point to move or to overcome the existing technological limits. This paper presents the development of the sequential process combination of laser micro structuring and micro milling.

2. Manufacturing processes

First of all, milling methods enable machining of metallic materials. In the field of micro manufacturing, milling technology is typically used for machining of tools, dies and prototypes. Although milling tools with diameters of down to 50 microns can be used reasonably under conventional manufacturing conditions, there are restrictions in relation to the structural shapes and dimensions which can be achieved. The minimum tool diameter limits the sizes of channels and the forming of an inside radius (see Figure 1a). Other restricting factors are the achievable aspect ratio, the low chip volume and the comparatively high processing time while using a very small micro milling tool.

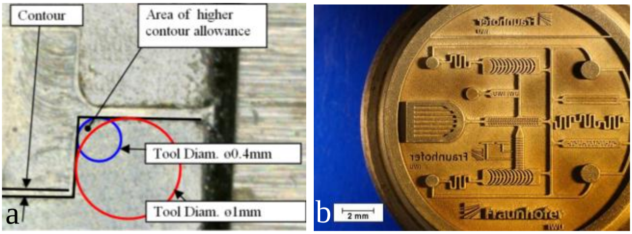

Figure 1: a) Machinable structural dimensions in relation to the tool diameter [3]; b) Embossing die with micro fluidic structures (silicon carbide)

Alternatively, laser machining can be used for micro structuring instead of micro milling. High focussing capability of the laser beam and high energy density enable manufacturing of different structural shapes and dimensions (see Figure 1b). Laser technology has been qualified as a micro structuring technology because it is characterized by high power density on a small spot area, its applicability to a wide variety of manufacturing processes and its suitability for machining difficult to machine materials such as ceramics, carbide and hardened steel with excellent productivity and surface quality [2]. The very small size of the laser spot diameter (tool diameter) is on the one hand a great advantage in the production of very small structural elements. On the other hand this fact is a disadvantage concerning the suitable ablation rates over a complete workpiece or operating range.

3. Combining micro milling and laser structuring

Sequential combination of micro milling and laser structuring enables structuring of very fine geometrical details with dimensions of < 10 µm and also processing of larger holohedral areas, enabling more efficient and faster machining of the complete component. Combined processing can be carried out in various process steps. The quality of the final result is defined by segmentation of the areas to be structured by the specific processes and by the processing sequence.

Holohedral areas can be defined which establish a border between the actual microstructures and the other (coarser) areas. First, the microstructured areas are processed by laser structuring. Then the other areas are processed using precision machining (see Figure 2a). Another option consists of segmenting the structured areas according to their structuring capability. In this method, the first process step comprises laser structuring of the fine structural details and of the areas that cannot be machined using defined diameters of the milling machine. Subsequently the other areas are processed by precision machining (see Figure 2b). Both of these options require laser structuring as a first process step. This is necessary because material removal to a defined depth is not possible using laser. Within the focused area the removal rate is almost identical, which causes simultaneous removal at different levels of depth.

Another structuring variant is to later introduce segmented microstructures into the pre-processed structured areas. In this context a large part of the actual geometry is finished by precision machining, followed by laser structuring to create the required microstructures in these geometries (see Figure 2c).

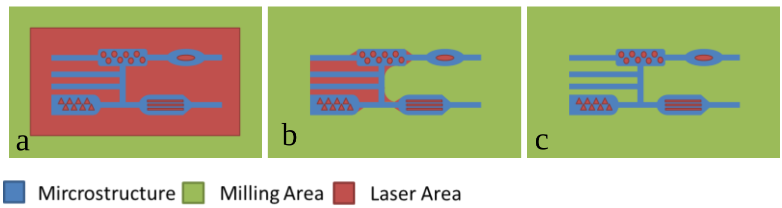

Figure 2: Different typs for combining laser machining and micro milling

In all three process variants, it is decisive to exactly position the individual areas of laser and milling to one another. At structural dimensions < 20 µm, the accuracy requirements are often below +/- 1 µm for the positioning of the areas to one another.

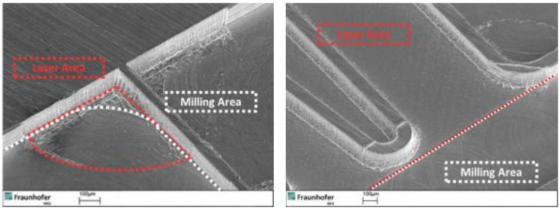

Figure 3: Excamples for combined manufactured microstructures

Due to the type of process, different surface characteristics result in the structuring processes of removal and machining. On the one hand this can be used to achieve defined surface properties. On the other hand it is possible to specifically rework the surfaces using laser in order to obtain defined roughness profiles. This is possible, among other things, by using a defined laser polishing.

4. Conclusions

In order to realise defined microstructures, which are deduced by forms and dimensions of medical micro fluidic systems, the workpiece geometries are processed by micro milling and laser machining as well as the combination of these two processes. This shows that very fine geometries could not be manufactured by micro milling.When using laser machining of large areas, processing times are very high. Combined manufacturing of both processes allows overcoming these disadvantages. Yet a different surface shape is apparent (roughness, surface structure, sub-structure) based on the different machining processes. Through determined modification of the process parameters and selective reworking it is possible to generate comparable surface structures. Furthermore it is possible to affect the characteristics of the surfaces. This can be used to influence the flow characteristics inside micro fluidic systems.

Thus, the combined work with laser structuring and micro milling enables not only reduction of processing time and the manufacturing of micro structures, but it also allows to realise new functionalities of fluidic systems by a defined surface modification already in the mould.

References:

[1] Youn, S.W.; Takahashi, M.; Goto, H.; Maeda, R.: Microstructuring of glassy carbon mold for glass embossing, Microelectronic Engineering 83 (2006) 2482-2492 Erlangen, (Physics Procedia 5.2010, Nr.1) pp.261-268

[2] Gillner, A.; Holtkamp, J.; Hartmann, C.; Olowinsky, A.; Gedicke, J.; Klages, K.; et al.: Laser applications in microtechnology, Journal of Materials Processing Technology 167 (2005) 494-498.

[3] Schubert, A.; Schneider, J.; Eckert, U.: Influence of special milling strategies on accuracy and surface quality of microstructured forms and prototypes, 3rd International Conference on High Speed Forming, March 11th -12th, 2008, Dortmund, 131 – 140