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INDUSTRIAL LASER MICRO SINTERING

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Abstract

As mechanical engineering industry encounters a growing demand of µm-sized or µm-structured components for an increasing range of applications, miniaturization is presently ranking among the most important goals in product and tool development.

Compared to still higher resolving techniques, selective laser sintering (SLS) still bears the advantages of relatively low production cost and short processing times even for series productions of micro parts. Furthermore, next to prismatic or tapered microstructures, undercuts and hollows can be realized.

Until recently commercial SLS units were unable to generate micro parts smaller than 100 µm. A novel modification of SLS together with a new setup, developed by Laser Institut Mittelsachsen e.V, extends the resolution to less than 30 µm with a minimal roughness of 1.5µm. The technique has been upgraded and successfully applied to produce micro tools or micro-components for tools from powders of refractory as well as lower melting metals in steps of 1µm thick sintered layers.

Based on this process and device, 3D-Micromac AG (Chemnitz, Germany) launches into the market a commercial system, which, on an industrial scale, performs selective laser sintering of solid and structured metal and in future also ceramic parts.

Introduction

Selective laser sintering (SLS), a familiar technique in rapid prototyping and rapid tooling, was heretofore preferentially applied for the generation of macroscopic freeforms. Commercial devices with a laser focus diameter of 40-500 µm still do not allow generation of micro parts smaller than 100 µm. In 2003 the Laser Institut Mittelsachsen e.V. in Mittweida, Germany, has reported a procedure [1,2] and a sintering machine [3], which makes feasible the generation of solid and structured parts out of metals and ceramics by direct selective laser sintering. An achieved aspect ratio of 12 taken into account, the resolution of less than 30 µm and a minimum surface roughness of 1.5 µm qualifiy the technique for generative precision tooling. The process, commonly referred to as "laser microsintering" is now launched into the market as "microSINTERING".

As SLS is a layer wise material structuring process, the approach of finer details requires thinner layers and consequently powders with smaller grain sizes. Because of the higher reactivity of finer grained solids the realization of these requirements is not always trivial. Precautions have to be taken to avoid corrosion of the powder by oxygen or humidity. Moreover finer powders often cause packing problems. Layers of those materials are very loose due to prevailing inter particle forces. In order to avoid agglomerates, special raking strategies have to be employed. The remaining lack of layer density has to be taken account of by an adequate laser sintering regime.

To overcome the difficulties from oxidation and humidity, the complete process was transferred into a vacuum tight chamber [4]. The obtained structures show a maximum resolution of less than 30 µm for overall resolution, of 20 µm for ligaments and of 10 µm for notches at aspect ratios of 12 and above, and presently a minimal roughness R_a of 1.5 µm can be achieved.

Process Assembly

Sinter Chamber

The process assembly [Fig.1] consists of the sintering chamber [Figs. 2,3], an attached turbo molecular vacuum pump, a ScanLab beam scanner with a scan field of 25 x 25 mm^2, a Q-switched Nd:YAG – laser (λ = 1064 nm) with an output of 0.1-10 W in TEM_{00}

mode and 0.5-50 kHz pulse frequencies, gate valves for various shielding and reaction gases as well as the power supply and the control unit for the coater and piston drives.

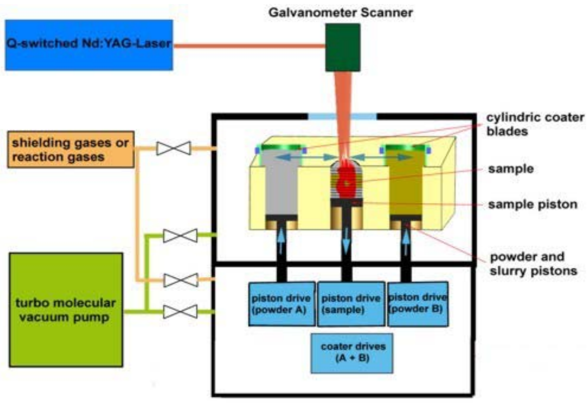


Figure 1 Schematic set-up for laser microsintering

The sintering chamber, where the process takes place, is a vacuum tight stainless steel casket, the lid of which has an integrated quartz glass window with transmission for the applied laser radiation. The casket has electrical feed throughs for the drives and an internal process observation camera.

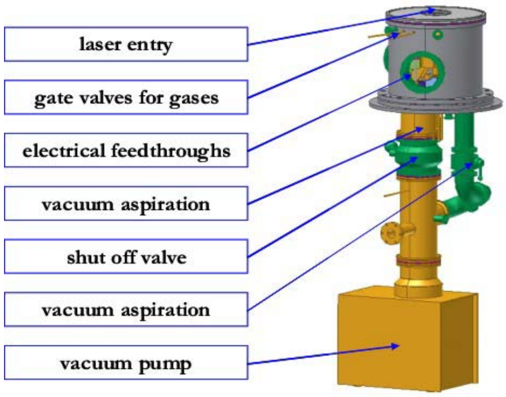


Figure 2 View of the chamber with vacuum pump

Several valves allow for the exchange of the shielding and reaction gases. By major and minor connections respectively, the pump and a manometer are attached to the upper and the lower segment of the chamber. This bisection allows the drives and the controls to be kept unaffected by the reaction atmosphere.

The process platform is bears one or more cylindrical bores for the powder piston and one for the sample piston. Each piston has its separate drive. [Fig. 1]. Two or more rakes sweep the powder materials with a circular motion onto the sample piston. The blades of the rakes are metal cylinders with a sharpened edge.

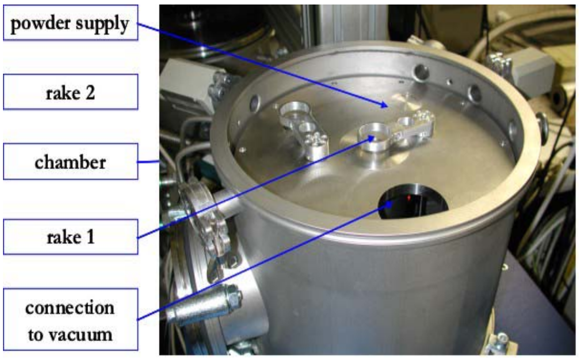


Figure 3 View upon process platform of the chamber

Because of their geometry the rakes also serve as intermediate powder reservoirs [Fig.4]. The position of the blade is manually adjustable; it is supposed to run as low over the platform surface as possible. Thus the waste of powder during a generation cycle is minimized .The pistons are tight for powders and liquids, which allows to process also emulsions and ceramic slurries.

The sinter chamber can be evacuated by the attached turbo molecular pump down to pressures of 10^{-3} Pa and it can be charged with shielding gases or reaction gases at any pressure in the range between 10^{-3} Pa up to $4x10^{5}$ Pa. A second, chemically resistant, pump can be connected to the chamber and, with a system of flow controls and pressure reducers, reaction gases can be flushed through at pressures of ≥ 1 Pa, which makes the device applicable for laser chemical vapor deposition (Laser CVD).

Figure 4 Ringblade serves as rake and powder storage

The proprietary software STL Converter that was developed especially for this purpose controls the sinter process. STL – data can be processed with a high resolution on a micrometer scale. Especially curves are executed at fast rates with high precision. Outline and filling parameters can be adjusted arbitrarily. Another - self-developed - program allows flexible control of the raking routine. The programs are accessed by the software via an interface, which facilitates automatic performance of a complex SLS - process.

Continuously repeated calibration of the scanner is integrated into the software accounting for the fidelity and precision of the technique, even at high aspect ratios.

Materials

For the generation of metallic free forms single component powders were used (Table 1). In addition, metal sintering was performed with blends of a refractory and a lower melting metal. For special tools this turned out to be suitable.

All metals are relatively inert materials at low and normal temperatures. When processed with laser radiation under a normal atmosphere, however, most of them show considerable oxidation.

Direct sintering of ceramics is probed with aluminium nitride powder and a porcelain raw material as a nonoxide ceramic and an oxide ceramic with a glassy component respectively. Selective reaction sintering is being done with aluminium powder under nitrogen.

Table 1 Processed Metal Powders

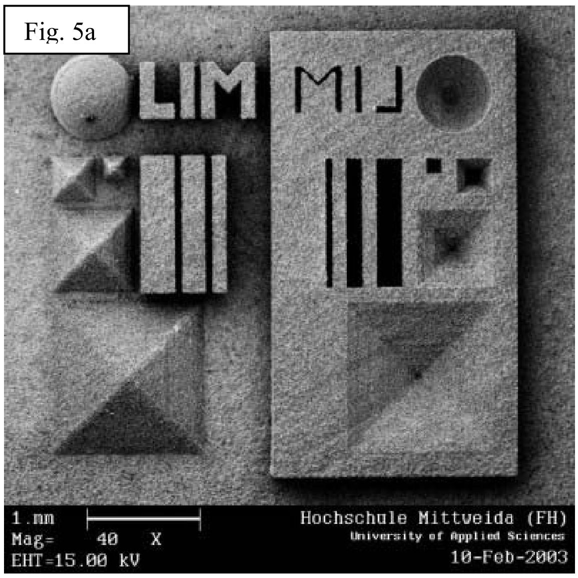
single component powders material	blends material
Tungsten	Copper/Tungsten
Aluminium	Aluminium/Tungsten
Copper	Copper/Molybdenum
Silver	Aluminium/Molybdenum
Titanium	
Molybdenum	
Iron	
Steel	

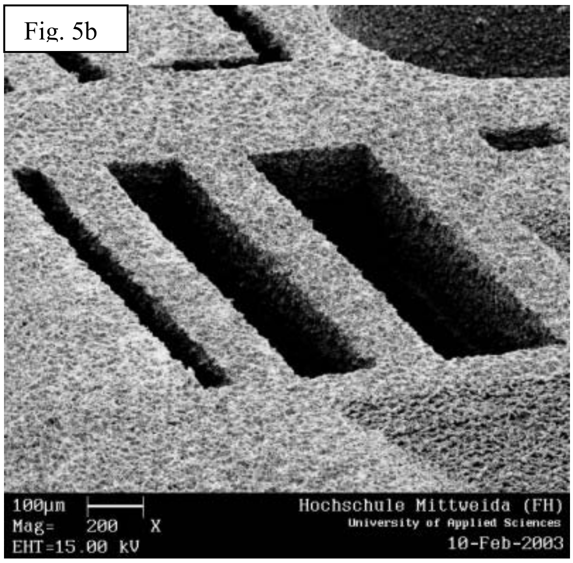
The results presented in this article confine to selective sintering of metal powders, especially tungsten.

Performance of the technique

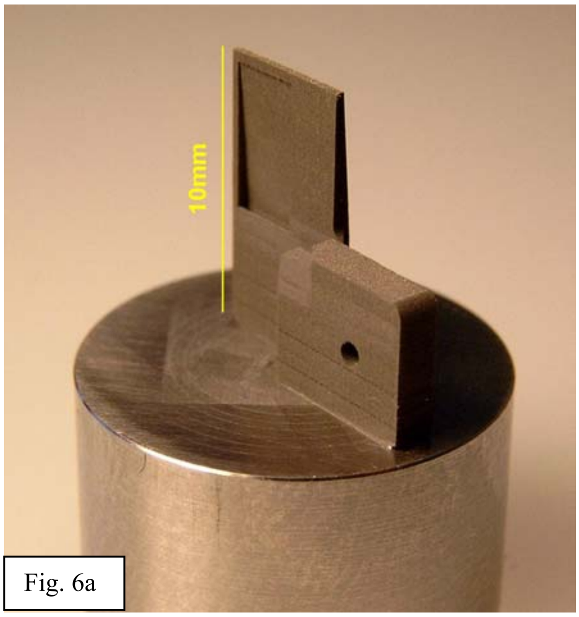
With a special sintering regime prismatic and tapered microstructures were generated from tungsten and other metal powders [Figs. 5]. The detail blow up [Fig. 5b] shows a notch with a width of 40 µm, the height of the structure is 400 µm. Considering the even narrower notches of the inserted letters in Fig. 5a, the samples evidences an obtained aspect ration of > 10.

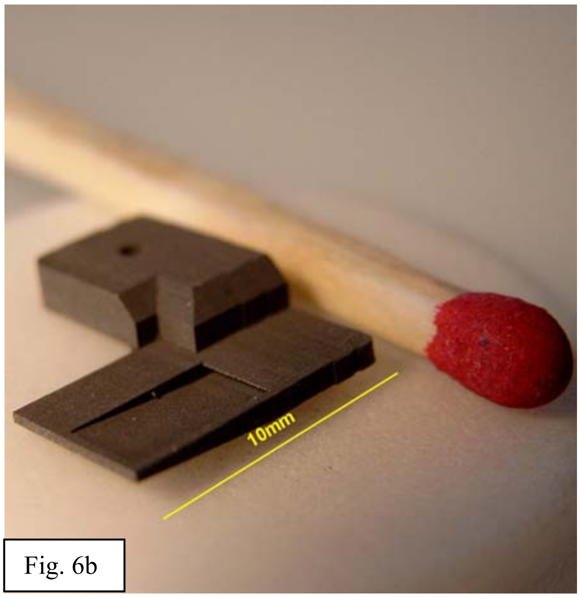
Fig. 6 shows the first functional tool generated by laser microsintering. It contains a slit with an open width of 480 µm and a length of 3.75 mm, which is connected to a circular window (diameter: 1 mm) by a tunnel through the solid body.





Figs. 5 SEM views of prismatic and tapered micro structures from 0.3 µm tungsten powder





Figures 6 A functional freeform was generated, loosely attached to a stainless steel substrate (a). The freeform was dissevered easily from the substrate (b).
Picture by courtesy of MiLaSys Technologies GmbH

The reported the roughness values of the tool are shown in Table 2.

Table 2 Surface Roughness (R_a)

Surface Type	horizontal	vertical	separation cross section
Grain Size	5 µm	3.5 µm	7 µm

Meanwhile surface qualities have been improved yet to roughness values of as low as 1.5 µm [Fig. 7]. Figures 8 and 9 show examples of undercuts generated from tungsten without the employment of support structures.

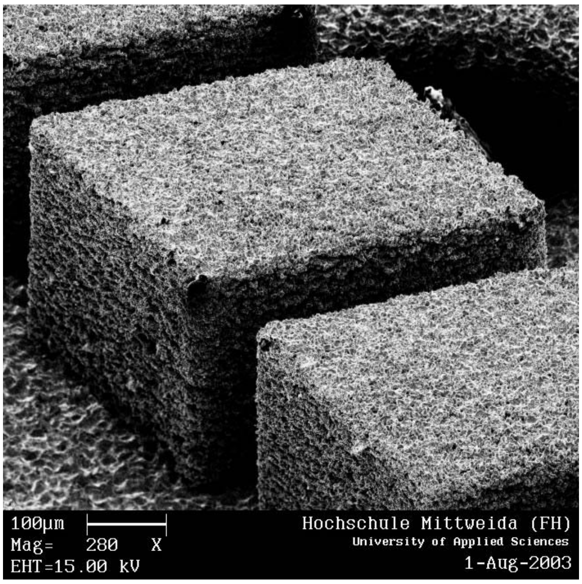


Figure 7 Cube with a roughness Ra of 1.5 µm

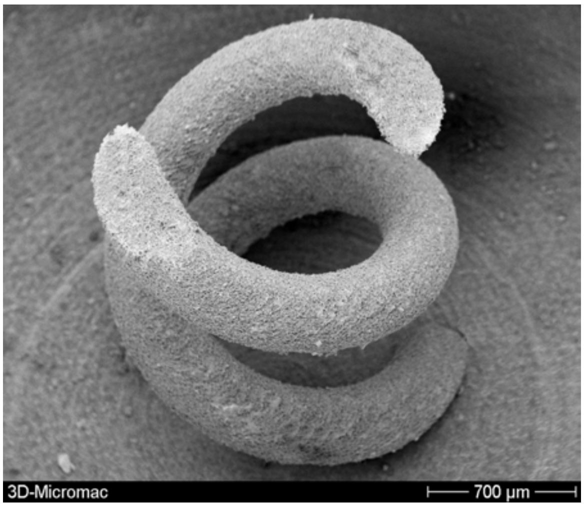


Figure 8 Bihelical structure as an example for undercuts, built without a support structure

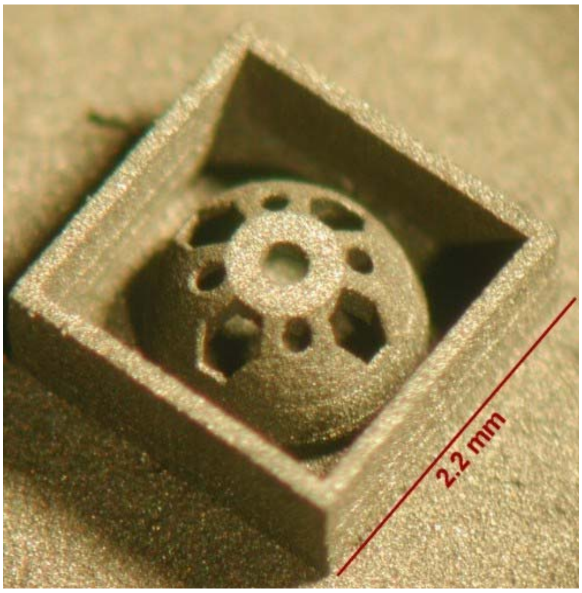


Figure 9 Open work semisphere. Built without a support structure

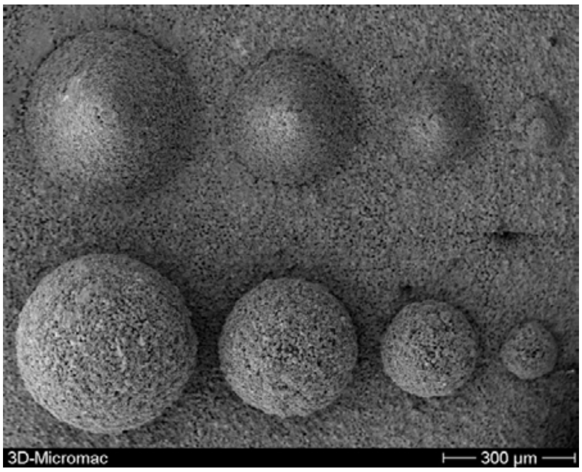


Figure 10 Spheres and cones

The spheres and cones in Fig. 10 give another example of the resolution.

Conclusion and Perspectives

Since its introduction in May 2003 laser microsintering has gained advertence and acknowledgement among toolmakers and users. The once innovative set up - consisting of a hermetically closed sinter chamber and a special rake – which already fitted the needs for the handling and selective sintering of sub-µm grained metal powders - has been upgraded to higher efficiency and industrial applicability. The specific procedure including the laser sintering regime has become a reproducible routine by which functional micro-freeforms are obtained from a number of powder materials. Ceramics laser microsintering is still in development. The ideas and applications of the innovation are registered in Germany and worldwide as patents and utility models.

Figure 8 Prospective design of the commercial microSINTERING system

Appreciations

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